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CANMET
NATIONAL URANIUM
TAILINGS PROGRAM

CONTRACT REPORT NO. OSQ83-00279

EVALUATION OF FLEXIBLE MEMBRANE LINERS AS LONG·TERM BARRIERS FOR URANIUM MILL TAILINGS. PHASE 1

VOLUME I OF 2
MAIN REPORT

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MICROMEDIA

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

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EXECUTIVE SUMMARY

Introduction

The National Uranium Tailings Program has commissioned a study to evaluate flexible membrane liners (geomembranes) as long-term barriers for Canadian uranium mill tailings. Golder Associates, together with their subconsultants Ontario Research Foundation and SENES Consultants, have been retained by Supply and Services Canada to carry out Phase I of the study.

This study reviews the common liner types and addresses flexible liners (polymeric membranes and asphalt) in detail. Liner fabrication, design, installation, and performance are reviewed. Conceptual designs are presented for basins to accommodate 20 years accumulation of uranium tailings from mills in Elliot Lake and southeastern Athabasca.

The study concludes with an outline of a proposed Phase II test program to carry out a detailed laboratory evaluation of candidate materials.

Liner Types

Nine polymeric and three asphalt liner types have been considered with respect to the physical and chemical environment in the uranium producing areas of Canada. All materials indicate good chemical resistance to uranium wastes but are subject to installation problems.

The liner types considered are:

1. Polyethylene (PE)
2. High Density Polyethylene (HDPE)
3. Chlorinated Polyethylene (CPE)
4. Chlorosulphonated Polyethylene (CSPE)
5. Polyvinyl Chloride (PVC)
6. Ethylene Propylene Diene Monomer (EPDM)
7. Butyl Rubber
8. Polychloroprene (CR)
9. Polyurethane
10. Asphalt Emulsions
11. Catalytic Airblown Asphalt
12. Asphaltic/Elastomeric Compounds

Surface sealants, including asphalt, show very low laboratory permeabilities but are subject to variable rates of application, are difficult to inspect during installation and are susceptible to damage due to differential movements, equipment traffic and cyclical climate effects including freeze-thaw cyclic loading. Asphaltic membranes must be provided with a soil cover.

Polymeric membranes offer wide ranging chemical resistance and are readily inspected. However, they are susceptible to damage during installation largely due to improper subgrade preparation and vehicular traffic. They require very careful installation and their performance is dependent on careful and successful field seaming. Field seaming is, in general, a detailed and sensitive operation. Weather, including temperature and precipitation, is generally the governing factor. In this regard, the elastomeric liners considered in this study, namely, Butyl, Polychloroprene and EPDM would appear to present the most problems in field seaming. Of the remaining liner types considered, successful field seaming has been demonstrated with HDPE, PE, CSPE, CPE and PVC. It is noted however, that there are serious concerns about the long-term weatherability of PVC and PE.

There are no standardized material specifications for polymeric or asphaltic membrane liners in either Canada or the U.S.A. However, recently developed documents by the National Sanitation Foundation (NSF) offer some promise of standardization. It is recommended that the NSF standards be used when specifying minimum material properties.

Liner Environment

The environment in which the tailings basins are constructed is an important aspect of liner requirements. Tailings basins in Elliot Lake and southeastern Athabasca would typically be situated in topographic lows with groundwater levels at or near ground surface, Sites would typically be underlain by organic matter, soils of moderate permeability and moderate to low permeability bedrock.

A significant chemical characteristic of the Elliot Lake uranium tailings leachate is the potential for oxidization of sulphide bearing minerals and the generation of sulphate rich, acidic porewater. As a result, the porewater could contain some dissolved radionuclides and heavy metals from the tailings.

Liner Installation

Proper subgrade preparation and construction is crucial for a successful liner installation and would typically consist of subexcavation of compressible materials, sterilization of the subgrade, removal of all roots, sticks, stones and debris, grading and proof-rolling, and installation of the sand cushion, liner and soil cover. Installation of the liner and field seaming should be carried out by approved installers meticulously following liner supplier instructions.

Soil cover is desirable but will require liner inclinations flatter than about 3 horizontal to 1 vertical.

Liner Performance

With the exception of polyurethane the base polymeric resins and asphalt show promise for long term resistance to the major anticipated constituents of uranium tailings. Caution should be noted with regard to the following:

- CPE may be affected by weak sulphuric acid solutions
- while not employed at Elliot Lake, kerosene is used for solvent extraction in some milling operations and was specified for consideration in this study. Most of the liners will offer satisfactory resistance to the low kerosene concentrations anticipated.
- most liners would be adversely affected by high kerosene concentrations associated with accidental spillage.

Compatibility testing carried out by Pacific Northwest Laboratories (PNL) on CSPE, PVC, HDPE and Catalytic Airblow Asphalt in the presence of simulated acidic uranium tailings leachate was reviewed. The data indicates that, with the exception of PVC, these materials were relatively unaffected by the leachate for the short test periods.

A review of published information addressing the effects of high levels of gamma radiation on the physical properties of polymeric liners indicated that HDPE was least effected, followed closely by CSPE, EPDM, CPE and CR. PVC and Butyl showed the greatest reaction to gamma radiation exposure. PNL estimates of the effect of gamma radiation on asphalt indicated that no physical defects were observed under the conditions of testing.

Thin flexible membrane liners are susceptible to overstressing by strains associated with large differential deformations in the subgrade. It will therefore probably be necessary to subexcavate and replace compressible materials encountered over the subgrade prior to liner installation. Similar concerns exist for liners placed on slopes and dam sections and where there is a potential for excess hydrostatic or gas pressure buildup beneath the liner.

Release Rates

Seepage through liners is primarily through liner defects. A rational approach to evaluating apparent or field liner permeabilities is through detailed monitoring of existing installations. Review of such data was initiated during this study.

Estimates of liner release rates were undertaken assuming permeable subsurface conditions (permeability greater than 1×10^{-4} cm/sec) and tailings permeability of 1×10^{-5} cm/sec.

The analyses indicate that an asphaltic membrane would reduce seepage to about 50 per cent of an unlined basin for a field liner permeability of 1×10^{-8} centimetres per second. Polymeric liners with an effective permeability of 1×10^{-10} centimetres per second would reduce seepage to less than 10 per cent of an unlined basin.

Costs

Cost estimates for lined tailings basins indicate that while liner costs are large, they are overshadowed by the cost of the related civil works. Asphalt, CSPE and HDPE liners, installed at Elliot Lake, are estimated to cost 1/5 to 1/3 of total facility costs of $74 to $89 million.

The reduced tailings volumes associated with the high grade ore in southeastern Athabasca results in substantially lower liner and impoundment facility costs. Asphalt, CSPE and HDPE liners are estimated to cost 1/5 to 1/3 of total facility costs of $15 to $17 million.

Warranties provided by liner suppliers only cover a portion of the cost relating to supply and installation of the membrane. They do not cover the consequential costs of failure or the cost of related civil works. These latter costs alone can exceed liner costs by 3 to 4 times.

Phase II Test Program

In order to select and predict with reasonable confidence long term liner performance, it is necessary to carry out further study. A study has been proposed which would consist of detailed laboratory testing and continuation of the industry user survey. Six candidate materials would be initially screened. Final accelerated testing would be carried out on 3 liner materials, at 4 temperatures, 3 strain conditions, and at 5 points in time. This study would require 2½ years with an estimated cost of $439,000.

It is recommended that an expanded survey of industrial users of flexible liners be carried out before finalizing the Phase II program.

RESUME EXECUTIF

Le Programme National de Rejets d'Uranium a commissioné une étude pour évaluer l'efficacité de l'utilisation des revêtements de membranes souples (géomembranes) comme cloisons à long terme pour les rejets de broyeurs d'uranium au Canada. Le mandat d'entreprendre la première étape de l'étude a été confié, par Approvisionnements et Services Canada, à Golder Associates, conjointement avec leurs sous-conseillers Ontario Research Foundation et SENES Consultants.

Cette étude passe en revue les genres de revêtement les plus connus et examine en détail les revêtements souples (membranes polymériques et d'asphalte). La fabrication, la conception, l'installation et la performance des revêtements sont révisées. Des études conceptuelles sont présentées pour de parcs à rejets qui permetteraient l'entreposage de 20 ans d'accumulation de rejets des broyeurs d'uranium qui se trouvent à Elliot Lake et au sud-est de l'Athabasca.

L'étude se termine avec une série de propositions pour la deuxiéme étape, ayant en vue d'entrepreднre un programme d'essai pour évaluer en laboratoire les matériaux considérés.

Genres de Revêtements

Neuf genres de revêtement polymérique et trois d'asphalte ont été considérés pour ce qui est de l'environnement physique et chimique qui se trouve dans les régions d'exploitation d'uranium au Canada. Tous les matériaux démontrent une bonne résistance chimique au rejets d'uranium mais ils sont sujets à des difficultés d'installation.

Les genres de revêtements considérés sont les suivants:

1. Polyéthylène (PE)
2. Polyethylène de haute densité (HDPE)
3. Polyéthylène Chloruré (CPE)
4. Polyéthylène Chlorusulphoné (CSPE)
5. Chlorure de polyvinyle (PVC)
6. Monomère Diène de Propylène Ethylène (EPDM)
7. Caoutchouc de Butyle
8. Polychloruprène (CR)
9. Polyuréthène
10. Emulsion D'Asphalte
11. Asphalte Catalytique A Pression D'Air
12. Composés Asphaltique Elastomérique

Les matériaux qui scellent la surface tel que les asphaltes, démontrent en laboratoire des perméabilités qui sont très basses. Cependant ceux-ci sont sujets à des taux d'application variables, ils sont difficiles à inspecter durant l'installation et ils sont aussi susceptibles aux dommages qui peuvent être occasionnés par les déplacements différentiels, la circulation de l'équipement et les effets cycliques du climat tel que le chargement cyclique des périodes de gèlement-dégèlement. Les membranes asphaltiques doivent être recouvertes de sol.

Les membranes polymériques offrent une grande résistance chimique et elles sont aisément inspectées. Toutefois, elles peuvent être endommagées durant l'installation due, en grande partie, à la préparation inadéquate du substratum et à la circulation. Leur installation doit être effectuée avec soin et leur performance dépend surtout de l'attention portée à la fabrication des joints sur chantier. En général, la fabrication de joints sur chantier est une opération délicate qui nécessite une attention scrupuleuse aux détails. Les conditions atmosphériques, soit la température et la précipitation, sont un des facteurs les plus importants qui affecte l'efficacité de ces joints. A ce sujet, les revêtements élastomériques considérés dans cette étude, soient le Butyle, le Polychloruprène et le EPDM, sembleraient poser le plus de difficultés pour ce qui est de la fabrication de joints sur chantier. De tous les autres revêtements considérés, des joints ont été effectués sur place, avec succés, en utilisant le HDPE, le PE, le CSPE, le CPE et le PVC. Il est à noté que la résistance du PVC et du PE aux conditions météorologiques dans le long terme demeure douteuse.

Présentement, il n'existe aucunes spécifications standardisées des matériaux pour les revêtements de membranes polymériques ou asphaltiques au Canada ou aux Etats Unis. Certains documents récemment produits par la Fondation National Sanitation offrent néamoins la possiblilité de normalisation. Il est recommandé que les standards NSF soient utilisés lors de la spécification des standards minimums des matériaux de revêtement.

Environnement des Revêtements

L'environnement où les parcs à rejets seront construits est un aspect important dans la détermination des exigences en termes de revêtements. En général, les parcs à rejets à Elliot Lake et au sud-est de l'Athabasca seraient situés dans des régions basses au niveau topographique où la nappe phréatique se trouve soi au niveau du sol ou très près. Les sites reposeraient typiquement sur des dépots de matières organiques, sur des sols de perméabilité modérée et sur des socles rocheux de perméabilité minime.

Une caractéristique importante du lixivage de rejets d'uranium à Elliot Lake est le potentiel pour l'oxidation de minerai sulfuré et la production d'eau interstitielle, riche en sulfate. En somme, l'eau interstitielle pourrait contenir des radionucliides dissolus et des métaux lourds provenant des rejets.

Installation des Revêtements

Pour assurer le succès de l'installation des revêtements il est absolument nécessaire que le substratum soit préparé et construit de façon adéquate. Ce travail consisterait typiquement de la sous-excavation de matières organiques compressibles, la stérilisation du substratum, l'enlèvement de racines, tiges, cailloux et tout autres décombres, le nivellement et la compaction du substratum, l'approvisionnement d'un coussin sablonneux, le tout finalement suivis du revêtement et le recouvrement de terre.

L'exécution des travaux d'installation du revêtement et la fabrication des joints doivent être entrepris par des travailleurs experts dans ce métier et les instructions des fournisseurs de revêtements doivent être suivies à la lettre.

Quoiqui'il soit préférable de recouvrir le revêtement de terre, les inclinaisons pour les pentes revêtues seront par nécessité au moins d'environ 3 horizontal pour 1 vertical.

Performance des Revêtements

Les résines de bases polymérique et l'asphalte semblent désirables pour ce qui est de leur résistance à long terme aux éléments constituants majeurs prévus pour les rejets d'uranium. Les précautions suivantes sont à notées:

- le CPE peut être affecté par de faibles solutions d'acide sulphurique

- le kérosène n'est pas utilisé à Elliot Lake mais il sert toutefois dans quelques opérations de broyeur et son utilisation a été considérée dans cette étude. La majorité des revêtements offrent une résistance satisfaisante aux faibles concentrations de kérosène prévues.

- la majorité des revêtements serait affectée de façon adverse par de fortes concentrations de kérosène qui pourraient se produire lors d'un débordement accidentel.

Des essais de compatibilité ont été effectués par Pacific Northwest Laboratories (PNL) sur le CSPE, le PVC, le HDPE et l'asphalte catalytique à pression d'air dans la présence de lixivage de rejets d'uranium acidique simulé. Les résultats de ces éssais ont été passés en revue au cours de cette étude et les données indiquent que ces matériaux sont relativement inaffectés par le lixivage durant les courtes périodes d'essais à l'exception du PVC.

L'information publiée au sujet de l'effet de niveaux supérieurs de rayonnement gamma sur les propriétés physiques des revêtement polymériques indique que le HDPE est le moins sensible suivis de près par le CSPE, le EPDM, le CPE et le CR. Le PVC et le Butyle démontrent la plus grande réaction à l'exposition du rayonnement gamma. PNL estime que sous les conditions des essais, aucune défectuosité n'a été observée par suite des rayonnement gamma sur l'asphalte. Les revêtements de membranes souples sont susceptibles aux sur-contraintes causées par les tensions associées aux grandes déformations différentielles du substratum. Précédent l'installation du revêtement il sera d'abord probablement nécessaire d'enlever et de remplacer les matériaux compressibles trouvés sur le substratum. Des considérations semblables existent pour les revêtements construits sur les pentes, sur les sections de barrages et aussi aux endroits où le potentiel existe pour l'accumulation de pression excessive d'hydrostatique ou de gaz sous le revêtement.

Taux D'Echappement

Les défectuosités des revêtements sont la cause primaire du suintement à travers ceux-ci. Une façon d'évaluer la perméabilité apparente ou sur place des revêtements est par un programme de surveillance détaillé des installations actuelles. Une revue de telles données a été entreprise au cours de cette étude.

L'évaluation des taux d'échappement des revêtement a été entreprise en présumant des conditions de substratum perméables (perméabilité supérieure à 1×10^{-4} cm/sec) et une perméabilité de rejets de 1×10^{-5} cm/sec. L'analyse indique qu'un revêtement de membrane asphaltique avec une perméabilité de 1×10^{-8} centimètre par seconde réduirait le suintement d'un basin de rejets sans revêtement a 50 pour cent. Les revêtements polymériques avec une perméabilitée effective de 1×10^{-10} centimètres par seconde reduiraient le suintement à un montant de moins de 10 pour cent de celui d'un basin sans revêtement.

Coûts

Les prévisions de coûts pur les parcs à rejets revêtus indiquent que quoique ceux-ci soient assez élévés, ces coûts sont néamoins minimes à comparer aux coûts des travaux civils associés aux projets. Le coût des revêtements d'asphalte, de CSPE et de HDPE qui ont été installés à Elliot Lake consiste approximativement de un 1/5 à 1/3 du coût global des aménagements ($74 à $89 millions).

Les volumes inférieurs de rejets qui sont associés avec les minerais à haute teneur du sud-est de l'Athabasca résultent en des coûts de revêtement et d'aménagements de stockage considérablement reduits. Ici, le coût des revêtements d'asphalte, de CSPE et de HDPE sont évalués, de 1/5 à 1/3 du coût global des aménagements ($15 à 17 millions).

Les garanties offertes par les fournisseurs de revêtements ne couvrent qu'une portion des coûts reliés à l'approvisionnement et l'installation des membranes. Ils ne suffisent pas lorsqu'il s'agit de couvrir le coût d'une défaillance du revêtement ou le coût des travaux civils associés aux projets. Le coût de ces travaux, par exemple, peut être de 3 à 4 fois plus élevé que le coût des revêtements.

Programme D'Essai - Deuxième Etape

Afin de choisir et de prédire, avec un certain niveau de confiance, la performance à long terme d'un revêtement, il est nécessaire d'entreprendre une étude plus approfondie. Cette étude consisterait d'essais détaillés en laboratoire et de la continuation du sondage des utiliseurs de l'industrie de revêtement. Au début, six matériaux seraient considérés. Par la suite, des essais définitifs et accélérés seraient entrepris sur trois matériaux de revêtement, à 4 niveaux de température, à 3 niveaux de tension et à 5 intervalles de temps. Cette étude serait effectuée au cours d'une période de 2½ ans, le coût projeté étant de $439,000.

Il est recommandé qu'un sondage de plus grande envergure des utiliseurs industriels de revêtements souples soit entrepris avant de compléter la deuxiéme étape du programme.

TABLE OF CONTENTS Page No.

EXECUTIVE SUMMARY

1. INTRODUCTION 1

2. TERMS OF REFERENCE 3

3. OVERVIEW OF LINER TYPES 6

3.1 General 6
3.2 Polymeric Membranes 7
3.3 Surface Sealants 9
3.4 Native Soils 12
3.5 Soil Additives 14
3.5.1 Cement 15
3.5.2 Lime 15
3.5.3 Bentonite 16
3.5.4 Dispersants 17

4. POLYMERIC MEMBRANES 19

4.1 Introduction 19
4.2 Manufacture 20
4.2.1 Description of the Polymeric Liner Industry 20
4.2.2 Polymerization 21
4.2.3 Film Manufacture 21
4.2.4 Liner Fabrication 24
4.2.5 Reinforcement 28
4.2.6 Quality Control 30
4.3 General Characteristics of Liner Types 33
4.3.1 Polyethylene (PE) 34
4.3.2 High Density Polyethylene (HDPE) 36
4.3.3 Chlorinated Polyethylene (CPE) 41
4.3.4 Chlorosulphonated Polyethylene (CSPE) 41
4.3.5 Polyvinyl Chloride (PVC) 45
4.3.6 Ethylene Propylene Diene Monomer (EPDM) 47
4.3.7 Butyl Rubber 50
4.3.8 Polychloroprene (CR) 52
4.3.9 Polyurethane 54
4.4 Liner Material Specifications 56

TABLE OF CONTENTS (Continued) Page No.

5. ASPHALTIC MEMBRANES 78

- 5.1 Introduction 78
- 5.2 Asphalt Emulsions 81
- 5.3 Catalytic Airblown Asphalt 82
- 5.4 Asphaltic/Elastomeric Compounds 84
- 5.5 Material Specifications 88

6. LINER ENVIRONMENT 91

- 6.1 General 91
- 6.2 Background 92
- 6.3 Site Considerations 94
  - 6.3.1 Introduction 94
  - 6.3.2 Site Conditions and the Requirement for Seepage Barriers 94
  - 6.3.3 Elliot Lake Area 96
  - 6.3.4 South Eastern Athabasca Region 102
  - 6.3.5 Other Uranium Producing Areas 113
- 6.4 Characteristics of Uranium Tailings 117
  - 6.4.1 General 117
  - 6.4.2 Background 117
  - 6.4.3 Physical Properties 120
  - 6.4.4 Chemical Properties 123

7. CONTAINMENT FACILITY DESIGN AND LINER INSTALLATION 129

- 7.1 General 129
- 7.2 Site Selection 132
- 7.3 Engineering Design 133
- 7.4 Liner Fabrication 134
- 7.5 Subgrade Preparation 135
  - 7.5.1 Clearing Grubbing and Stripping 135
  - 7.5.2 Sterilization of Subgrade 136
  - 7.5.3 Excavation and Filling 136
  - 7.5.4 Liner Subdrainage and Gas Venting 137
  - 7.5.5 Finishing 138
- 7.6 Liner Installation 139
  - 7.6.1 Polymeric Liners 139
  - 7.6.2 Field Seaming 143
  - 7.6.3 Asphalt Liners 144
- 7.7 Soil Cover 146
- 7.8 Quality Control 148

TABLE OF CONTENTS (Continued) Page No.

8. PERFORMANCE CRITERIA AND FAILURE MECHANISMS 152

- 8.1 Introduction 152
- 8.2 Performance Criteria 152
- 8.3 Liner Compatibility and Durability 153
  - 8.3.1 General 153
  - 8.3.2 Polymeric Liners 156
    - 8.3.2.1 General Chemical Resistance 156
    - 8.3.2.2 Resistance to Uranium Tailings 161
    - 8.3.2.3 Resistance to Radiation 164
  - 8.3.3 Asphaltic Liners 168
    - 8.3.3.1 General Chemical Resistance 168
    - 8.3.3.2 Resistance to Uranium Tailings 169
    - 8.3.3.3 Resistance to Radiation 170
- 8.4 Failure Mechanicms 171
  - 8.4.1 Physical Failure 171
  - 8.4.2 Chemical Failure 175
  - 8.4.3 Biological Failure 176
- 8.5 Mechanisms and Rates of Liner Degradation 176

9. RESULTS OF INDUSTRY SURVEY 185

10. RELEASE MECHANISMS AND RATES 192

- 10.1 Release Mechanisms 192
- 10.2 Release Rates 193
- 10.3 Elliot Lake 196
- 10.4 Southeastern Athabasca 198

11. LINER COSTS 200

- 11.1 Elliot Lake 200
  - 11.1.1 General 200
  - 11.1.2 Drainage 201
  - 11.1.3 Site Preparation 201
  - 11.1.4 Dams 202
  - 11.1.5 Liners 202

TABLE OF CONTENTS (Continued) Page No.

11.2 Southeastern Athabasca 204
  11.2.1 General 204
  11.2.2 Site Preparation 205
  11.2.3 Dams 205
  11.2.4 Liners 205
  11.2.5 Soil Cover 205
11.3 Summary 206

12. WARRANTIES 209

12.1 Polymeric Liners 209
12.2 Asphalt 212
12.3 Summary 212

13. TEST PROGRAM FOR THE LONG-TERM STABILITY OF FLEXIBLE LINERS - PHASE II 214

13.1 Requirements of Test Program 214
13.2 Approach 214
13.3 Methodology 216
13.4 Anticipated Degree of Success 217
13.5 Program Costs 218

14. CONCLUSIONS AND RECOMMENDATIONS 221

BIBLIOGRAPHY 224

LIST OF TABLES Page No.

TABLE 4.1 Methods of Constructing Geomembrane Seams 26

4.2 NSF Recommended Test Methods Thermoplastics 66

4.3 NSF Recommended Test Methods Crystalline Thermoplastics 68

4.4 NSF Recommended Test Methods Supported Thermoplastic Elastomers 70

4.5 NSF Recommended Test Methods Elastomers 72

4.6 Properties of Polymeric Liner Membranes Installed as Barriers 74

4.7 Specifications for High Density Polyethylene Supplied By Gundle Lining Systmes Ltd. 76

4.8 Specifications for 60 Mil Reinforced Industrial Grade Hypalon Supplied by J.P. Stevens & CO. Inc. 77

5.1 Tentative Specifications for Asphalt for Hydraulic Membrance Construction as of December 1965 89

5.2 Tentative Specifications for Asphalt for Use in Water Proof Membrane Construction for Canal, Ditch, or Pond Lining 90

6.1 Chemical Characteristics of Tailings Porewater Elliot Lake Area 124

6.2 Mill Final Effluent Analyses Midwest Uranium Project 127

7.1 Available Non-destructive Test Methods for Evaluating Polymeric Lining Seams 151

LIST OF TABLES (Continued) Page No.

TABLE 8.1	General Chemical Resistance of Polymeric Liner Materials	159
8.2	Effect of Gamma Radiation on Physical Properties of Selected Polymeric Liners	166
8.3	Mt. Elbert Forebay Reservoir Test Section Results	182
9.1	Liner User Survey	188
11.1	Liner Cost Summary (Elliot Lake)	207
11.2	Liner Cost Summary (Southeastern Athabasca)	208
13.1	Phase II Test Program Cost Summary	220

LIST OF FIGURES

FIGURE 1. Structure of Polymeric Liner Industry

2. Areas in Canada Favourable for the Occurrence of Uranium Deposits

3. Grain Size Distribution - Elliot Lake Tailings

4. Grain Size Distribution - Midwest Lake Tailings

5. In Situ Properties of Silt and Sand Tailings

6. Results of Industry Survey of Flexible Liner Users

7. Plan of Tailings Basin

8. Cross-Sections A-A and B-B

9. Cross-Section C-C

10. Schematic Illustration of Dam Section

11. Installed Cost of Flexible Membrane Liners

12. Estimated Release Rates for Polymeric in Asphaltic Liners (Typical of Elliot Lake)

13. Estimated Release Rates for Polymeric in Asphaltic Liners (Typical of South-eastern Athabasca Region)

14. Accelerated Testing

LIST OF APPENDICES

APPENDIX A Statement of Work

B Polymeric Flexible Membrane Liners Material Property Specifications and Special Test Methods and Test Procedures National Sanitation Foundation (NSF) Standard No. 54

C Representative List of Organizations in Liner Industry

D Liner Suppliers

E Liner Users

F Typical Warranties

1. INTRODUCTION

Golder Associates has been retained by Supply and Services Canada to carry out Phase I of a study to evaluate flexible membrane liners (geomembranes) as long-term barriers for Canadian uranium mill tailings. The study was initiated by a request for proposal, DSS File No. 14SQ.23241-3-1662, to which Golder Associates, together with subconsultants, Ontario Research Foundation and SENES Consultants responded.

As outlined in the request for proposal, Phase I of the study involves the generation of an information base and focuses on commercially available flexible liners (also referred to as membranes or geomembranes), their properties, manufacture, installation, anticipated performance and associated costs. Phase I also includes the preparation of a technical proposal and cost estimate for Phase II of the study which would consist of a laboratory test programme to evalute the long-term performance of flexible liners exposed to selected wastes.

The information provided in this report has been collected from a number of sources including:

i) Industries with lined facilities in operation

ii) Manufacturers and suppliers of lining systems

iii) Canadian and United States government reports

iv) Independent publications

v) Internal files and private sources.

These sources vary widely in the nature, quality, and subjectivity of the information provided. This report attempts to present the gathered information in a comprehensive and objective manner.

The study commenced with a review of liner types presently in use and their general availability. Following initial discussions with the Scientific Authority (National Uranium Tailings Program), the following flexible liner types have been selected for relatively detailed consideration and are addressed in this report:

i) polyethylene (P.E.)
ii) high density polyethylene (HDPE)
iii) chlorinated polyethylene (CPE)
iv) chlorosulphonated polyethylene (CSPE) (commonly known by the Dupont trade mark-HYPALON)
v) polyvinyl chloride (PVC)
vi) ethylene propylene diene monomer (EPDM)
vii) butyl rubber
viii) asphalt

The report also addresses neoprene and polyurethane in somewhat less detail.

2. TERMS OF REFERENCE

The terms of reference for the Phase I study were outlined in the Statement of Work attached to the contract and included with this report as Appendix A. The terms of reference require preparation of an information base and recommendations for a Phase II test programme.

Phase I of the study focuses on the properties, manufacture, placement, performance and cost of flexible membrane liners. The study assumes that the liners are to be provided with a soil cover and that the materials may be used as both dam membranes and complete tailings basin liners. The study concentrates on the two main uranium producing areas of Canada namely; the southeastern Athabaska basin region of Saskatchewan and the Elliot Lake - Blind River area of Ontario. The study also addresses other potential uranium producing areas of Canada including areas of continuous permafrost.

The design period of consideration for this study is up to 1000 years.

Consistent with the terms of reference, the Phase I study includes the following:

i) A description of the properties of 8 commercially available materials which may be suitable as flexible liners for uranium tailings.

ii) A description of the manufacturing method for the resin and sheet for the materials selected for the study as well as the necessary quality control measures.

iii) A description of the site preparation and installation procedures required for continuous liners, including field seaming techniques and field quality control.

iv) Estimates of the rate of release of contaminants through the liners selected for study as a function of time.

v) A discussion, based on available information, of the anticipated failure mechanisms and rates of degradation of the liner materials in the expected field conditions, including a description of the potential failure mechanisms of factory and field seams.

vi) Estimates of the installation costs of the selected liner material at the two main uranium producing areas.

vii) The preparation of a technical proposal and cost estimate for the Phase II test programme.

There is presently only limited information available associated with the actual performance of flexible liners to contain uranium tailings. Based on the information collected in Phase I, a Phase II program has been proposed which will involve a detailed laboratory test programme and associated analyses. The test programme would be carried out on selected liner materials in contact with potential contaminants in order to assess failure mechanisms, degradation rates and rates of contaminant release.

3. OVERVIEW OF LINER TYPES

3.1 General

There are generally two major techniques utilized to minimize subsurface flow of contaminants from uranium mill tailings disposal facilities:(1)

i) techniques which take advantage of favourable site hydrogeology and subsurface soil and rock conditions to minimize contaminant transport

ii) techniques which involve the construction of barriers (pond liners) to contain and thus minimize the entry of contaminats into surface or groundwater.

Where less than ideal hydrogeological conditions prevail at a prospective waste disposal site, a reliable seepage control mechanism in the form of a pond liner is often considered.

A large variety of liner types may be considered during the selection of a liner material to meet specified criteria and installation requirements. Most of the available and generally flexible liner types are briefly addressed in the following sections with respect to their potential for application as tailings pond liners. For discussion purposes, liner materials are separated into four categories:

i) polymeric membranes

ii) surface sealants
iii) natural soils
iv) natural soils with additives

The purpose of this study is to study flexible membrane liners (geomembranes) whose base product is a synthetic polymer or asphalt.

3.2 Polymeric Membranes

The most common synthetic polymers presently used as base products in the manufacture of polymeric membranes may be classified as:

i) thermoplastics
ii) crystalline thermoplastics
iii) thermoplastic elastomers
iv) elastomers

The membranes manufactured from the above group of synthetic polymers offer considerable variation in their chemical and physical properties, methods of installation, costs and interaction with various wastes. In addition, there can be considerable variation in the membranes fabricated from the same polymer due to differences in compounding and methods of construction.

Collectively, synthetic liners display a number of advantages and disadvantages which may be summarized as follows:

Advantages

a) can contain a wide variety of fluids with minimum seepage due to very low reported permeabilities of typically 1 x 10^{-10} centimetres per second or less

b) have relatively high resistance to chemical and bacterial deterioration

c) are readily installed for many applications

d) are relatively economical to install and maintain.

Disadvantages

a) are relatively vulnerable to attack from ozone and ultra-violet light

b) have limited ability to withstand stress from heavy machinery

c) have not been in service long enough to evaluate long-term performance

d) are comparatively susceptible to laceration, abrasion and puncture

e) some materials are prone to cracking and crazing at low temperatures or stretching and distortion at high temperatures

f) although readily installed there are often difficulties associated with field seaming.

3.3 Surface Sealants

Sealants, many of which are sprayable, can be installed as flexible liners to provide impoundment and containment of wastes. Because these products are placed on the exposed soil surface of the containment area they are referred to as surface sealants. A number of products are available including:

- Alkyd
- Asphalt
- Concrete
- Epoxy
- Polyester
- Polysulfide
- Polyurethane
- Silicone
- Synthetic Rubber
- Thermoplastic Molten Sulfur
- Vinyl

These materials have, in general, been developed for applications such as caulking sealants, soil stabilizers, waterproof barriers, and corrosion protective coatings. Their application to date, for waste or tailings containment, is limited.

Surface sealants can be formulated to produce either flexible or rigid lining structures. As a class, these materials do not interact with the existing subgrade of the tailings ponds or dams, but provide a surface coating over the prepared subgrade.

Surface sealants can be installed with three basic techniques:

(i) In Situ Chemical Cure

The materials chemically cure or harden after being applied to the surface. These materials usually involve more than one specific chemical.

(ii) Heat Application

Materials which are solid in the desired operating temperature range are applied at elevated temperatures to improve ease of application.

(iii) Surface Drying

The material is formulated in a water emulsion or diluted in a solvent carrier for application. The carrier evaporates leaving a solid coating.

Combinations of the above techniques are also feasible in many cases. The object is to prepare the material for ease of application usually with conventional spraying equipment. The actual technique for application is a function of the specific material.

In some cases scrim (fabric reinforcement) supports are required for strength, while in others, the material must be placed on an additional impervious barrier to prevent interaction with the substrata. This is particularly true for some of the chemically cured coatings.

The primary advantages and disadvantages of surface sealants are:

Advantages

a) either sufficient flexibility to conform with or sufficient strength to support the design load bearing (pedestrian or vehicle traffic for example),

b) good weatherability and service life,

c) compatability with the stored product,

d) immunity to biological attack,

e) sufficient puncture and abrasion resistance,

f) capability of being placed with minimal defects

g) easily repairable, and

h) ease of application and produces an integral liner with no joints.

Disadvantages

a) Relatively difficult to regulate the rate of application and thus the thickness and uniformity of the sealant.

b) As a class these materials are relatively expensive. The high initial cost versus relative ease of application for the spray-ons should be considered for specific applications.

3.4 Native Soils

The obvious advantage of local native soils for use as containment pond liners is one of economics. The use of local soils would preclude the purchase and import of a synthetic or other form of liner. The costs of liner construction would be limited to the costs of preparing an existing deposit or the costs associated with mining a suitable local deposit and hauling and placing it at the chosen containment site.

The advantage of using a native soil liner would of course diminish as the distance of the suitable deposit from the disposal site increases.

Permeability of porous meria is defined by Darcy's Law which states that seepage velocity is linearly related to hydraulic head and gradient. Liquid viscosity and density will also influence seepage velocity but in most civil engineering applications the liquid is water and the minor variations in viscosity and density are ignored. By these assumptions permeability has units of velocity and is synonomous with hydraulic conductivity.

The most often cited disadvantage of native soil liners is their relatively high permeabilities compared to synthetic membranes. There is considerable variation in opinion on the required permeability for an effective liner ranging from 10^{-5} to 10^{-9} centimetres per second (1, 2, 3). A specified permeability in the order of 10^{-7} centimetres per second is often considered applicable for natural soil liners. Evaluation of natural soil for liners should consider, in addition to permeability, the thickness of the natural soil liner or deposit as well as its contaminant attenuation capacity and propensity for geochemical immobilization.

Due to their relatively low permeabilities, clay or soils with high clay content are commonly considered for use as liners. It is known, however, that the relatively low permeabilities of natural clays can be adversely affected by wastes with high cation content, low pH or organic liquid-bearing wastes (4).

The variable nature of natural soil deposits has also been cited as one of their disadvantages. Veins or stringers of more permeable materials may run through the deposit of otherwise suitable liner materials. These veins may provide conduits contributing to loss of leachate from the containment area and into the groundwater. This would not normally be a problem where the natural soil is excavated from a local deposit and placed in the containment area since the resulting mixing would rid the material of continuous stringers. Where a natural soil is to be utilized as a liner in situ and where stringers are a concern it would be necessary to properly rework the soil to an adequate depth to produce a homogeneous uniform liner. This would, of course, increase the cost of this method of waste containment.

3.5 Soil Additives

Soil stabilization using additives is defined as a treatment to modify the physical properties of the soil. Because of the great variability of soil types, no one additive is universal. The main properties of a soil which can be modified with additives are volume stability (shrinking and swelling), strength, permeability, durability, and a reduction in frost susceptibility.

The more common additives utilized to stabilize or alter the characteristics of soils include:

i) cement
ii) lime
iii) bentonite
iv) dispersants

Bituminous (asphalt) stabilization may be used in granular soils to increase strength and decrease permeability but bituminous stabilized soils have apparently not been used for liner construction in tailings basins. However, asphaltic membranes (surface sealants) have been used as liners and are discussed elsewhere in this report.

3.5.1 Portland Cement

Portland cement is the most common additive used to stabilize or improve soil properties. It has primarily been used for road construction but has been successfully used for water barriers(5). Most natural and processed soils can be treated with cement with the following exceptions:6)

i) highly organic soils

ii) clean gravel and crushed stone

iii) soils with in excess of 50 per cent passing the 200 sieve and with liquid and plastic limits in excess of 50 and 18 per cent, respectively.

The properties of cement stabilized soils depends on cement content and degree of compaction before hydration. Cement treated soils generally show increases in strength and durability. In cohesionless soils the permeability decreases with increasing cement content. Permeabilities for silty sand and fine sand soils treated with 2-6 per cent cement range from 10^{-6} to 10^{-7} centimetres per second(5, 7).

3.5.2 Lime

Stabilization with hydrated lime is similar to cement stabilization in that the same testing and construction techniques are used. It is less suitable for granular materials than cement and more effective on clayey soils. It is often used as a construction expedient to prepare soil for further treatment or to support construction traffic.

Lime is a well proven stabilizer against erosion and can be used to increase surface strength. Lime generally does not improve the liquid retaining properties of a soil; in fact lime may make a soil more permeable but probably not enough to render an otherwise acceptable soil unsuitable for liner construction. It is significant in relation to liners since lime could render an unsuitable clayey soil (very plastic and wet) suitable for liner or dam construction by increasing its strength without significantly increasing its permeability.

3.5.3 Bentonite

Bentonite is a naturally occurring inorganic swelling clay which is marketed under various trade names. Bentonite can swell up to 15 times its dry volume in water and when mixed with in situ soil can form a seepage barrier of low permeability.

The level of ionic salts found in certain wastes is often sufficient to reduce the swelling of bentonite and therefore reduce its effectiveness as a sealant. Even where the bentonite is prehydrated with fresh water, the presence of large quantities of dissolved salts could lead to the deterioration of the prehydrated clay. The use of specially formulated types of bentonite, such as "Saline Seal" marketed by American Colloid Company, reportedly assures that after prehydration, the bentonite remains swollen and does not deteriorate as rapidly when exposed to high levels of ionic contaminants.

The use of bentonite is usually restricted to sealing situations where the soil has a relatively high void ratio, such as in sandy and open textured soils, and where strength is not an important consideration. While soft and susceptible to traffic damage, a beneficial property of bentonite's plastic nature is its self-healing ability. When saturated the consistency of bentonite is such that minor breaks or tears will heal themselves.(8)

Permeability testing carried out by the American Colloid Company(9) indicates that sandy soils treated with 2 kilograms per square metre of Saline Seal worked into the top 50 millimetres of soil had permeabilities ranging from 4 x 10^{-7} to 1 x 10^{-7} centimetres per second. The liquid used represented up to 5 times the contaminant concentration (dissolved salts) of a sanitary landfill leachate. American Colloid Company also reports that for a polymer-bentonite sealant applied at rates of between 0.6 and 0.9 kilograms per square metre, permeabilities of between 1 x 10^{-6} centimetres per second and 1 x 10^{-8} centimetres per second, respectively, could be anticipated.

3.5.4 Dispersants

Dispersants are inorganic compounds which modify the interparticle forces associated with clay minerals such that compacted densities are increased. Dispersants have the effect of blocking the seepage paths with clay fines but they do not have a cementing effect and do not provide water repellency to the soil grains. Typical dispersants are tetrasodium pyrophosphate, sodium tripolyphosphate and sodium hexametaphosphate.

Because dispersants act by altering the surface characteristics of the soil, they work best with soils of high specific surface such as clays and silts and are ineffective with clean sands and coarse soils. Previous experience with dispersants where a 300 millimetre thick blanket of clayey till was treated with 0.1 per cent of sodium tetraphosphate indicated a decrease in permeability by an order of magnitude.(10)

Dispersants are commercially available and since they are used in trace quantities, they permit low cost treatment. For liner construction they could be used to decrease the permeability and frost susceptibility of fine grained soils. However, dispersants have a short life span, less than 10 years; this can be attributed to continual ion exchange, resulting in loss of swelling capacity, and the water solubility of salts.(11) In addition, the use of dispersants is relatively undeveloped and unproven for containment of uranium tailings.

4. POLYMERIC MEMBRANES

4.1 Introduction

Polymers are chemical compounds of high molecular weight. The synthetic polymers used to manufacture membranes or liners are generally classified as thermoplastics and elastomers. As noted in a previous section they may be further subdivided into crystalline thermoplastics and thermoplastic elastomers.

As a group, the basic advantages of polymeric membranes include very low permeability, the ability to conform to irregularities and relatively wide ranging chemical resistance. With respect to permeability, values for intact samples of polymeric liners in the order of 1×10^{-11} to 1×10^{-12} centimetres per second or lower are often quoted. It should be noted that these values for permeabilities of liner specimens are generally significantly lower than permeabilities considered operative or representative of installations as a whole. This very important aspect is addressed in more detail in subsequent sections of this report.

Polymeric liners are susceptible to damage during installation or to ground subsidence. They can also be punctured during operation due to gas build up. Finally, polymeric liners are particularly susceptible to poor seaming techniques.

The general characteristics of liner materials, particularly in terms of chemical compatability, are usually discussed in terms of the base polymer or raw material (ie. PVC, PE, CPE, CSPE etc.) used. The significant effects on compatibility of the various additives in the compounds which form the liners are generally not taken into account.

In this section the polymeric lining industry and the manufacture of the membranes are briefly discussed and general comments associated with the materials selected for the study are provided. Finally, liner properties provided by manufacturers and suppliers as well as from independent studies are addressed.

4.2 Manufacture

4.2.1. Description of the Polymeric Liner Industry

The structure of the polymeric liner industry is illustrated schematically on Figure 1 and can be seen to break down into four main segments; they are:

- raw material producers
- manufacturers of sheeting or roll goods
- fabricators of liner panels
- installation contractors

A particular company in the industry may perform two or more of these functions; e.g. a sheeting manufacturer might also fabricate and install pond liners. The interrelationship of these various groups is further discussed elsewhere in this report with respect to selection of manufacturers, fabricators and installers.

A list of polymer producers, liner manufacturers, fabricators and installers are included in Appendix C. Companies contacted during the current study are identified in Appendix D.

4.2.2 Polymerization

All thin membrane linings are made from materials that are the result of the chemical reaction called polymerization, wherein small molecules join together with themselves or other molecules to form long chain polymers. For example, when ethylene monomer is fed to the reactor, polyethylene resin is produced. Similarly when vinyl chloride monomer is fed in, polyvinyl chloride resin is the product. A combination of monomers can be mixed in the polymerizer to produce copolymers, tripolymers, terpolymers, and so on. Butyl rubber, for example, results from a copolymerization reaction between the monomers isobutylene and smaller amounts of isoprene.

4.2.3 Film Manufacture

Compounding

The raw resin manufacturer usually compounds the resins with basic additives such as antioxidants, heat stabilizers, flow modifiers, etc. These resins, including the basic additives, are shipped to processors to be converted into the final product.

Additional additives are usually included in the basic compounds by the processors. Additives which are typically compounded with the base resins are fillers, fibres, processing aids, plasticizers, carbon black, stabilizers, antioxidants and fungicides. Typical filler materials would include mineral particles, metallic oxides, ground polymers and/or sawdust with the ratio of filler to total polymeric compound (including filler) typically 0 to 20 per cent for thermoplastics and between 10 and 50 per cent for elastomers.(12) Processing aids are used to reinforce or soften the compound during manufacturing while plasticizers provide flexibility. The ratio of plasticizer to base product is typically 0 to 2 per cent for elastomeric compounds and can be up to 55 per cent for PVC compounds.(12) Carbon black is typically added to concentrations of less than 2 per cent for thermoplastics and up to 45 per cent for elastomers to provide colouring to resist the aging effects of ultraviolet light and for the case of elastomers, to increase stiffness.(12) Stabilizers and antioxidants help reduce aging and provide stability during manufacture and fungicides prevent fungal and bacterial attack.

Sheet Production

Following compounding, including the addition of additives, sheets are produced by calendering, extrusion or spread coating.

Spread coating which consists of spreading a polymer on a fabric or sheet of paper is seldom utilized for common liner materials so will not be discussed further.

Of the liner materials to be considered in this study only polyethylene is known to be produced by extrusion. In this process a molten polymer, usually of the polyolefin family, is extruded into a non-reinforced sheet.

Calendering is by far the most frequently used method of producing the sheets. Calendering consists of passing a heated polymeric compound through a series of highly polished steel rollers. Calendered unreinforced membranes are often produced by simultaneously running more than one sheet of compound through the calenders to minimize the effects of pinholes caused by grit or other impurities. Calendered reinforced membranes are produced by running sheets of compound and reinforcement through the calenders. A 3-ply membrane would have one sheet of reinforcement between two sheets of compound while a 5-ply membrane would have two sheets of reinforcement covered by and separated by three sheets of compound.

The membranes are usually manufactured in sheets typically 1.2 to 1.8 metres wide, but in some cases up to 10 metres wide, and in varying thickness. The thickness of the membrane is usually specified in mils which are units equal to thousandths of an inch (0.001 inches or 0.0254 millimetres).

4.2.4 Liner Fabrication

The membranes produced in wide (5 to 10 metres) and heavy rolls are generally shipped to the site to be field-seamed to produce the liner. The lighter narrower rolls would be shipped to a fabrication factory where they are factory seamed into large blankets. The size of the factory fabricated blankets is usually only limited by handling weight and dimension. The liner is fabricated on the site from either the larger rolls as noted above or the factory produced blanket.

The technique used for seaming the rolls or blankets in the field and factory is dependent on the composition of the liner material. Some materials can be seamed by a number of techniques. The methods of seaming are categorized as follows:

i) Thermal, including electronic (dielectric) bonding, hot air bonding, hot wedge or knife bonding.

ii) Solvents or cements including solvent bonding, bodied solvent adhesives, solvent cements and contact cements.

iii) Tapes only including polyethylene tape or uncured gum tape.

iv) Vulcanization using uncured tape or adhesives.

v) Extrusion or fusion welding.

vi) Mechanical (friction or sewn).

Of the above noted methods, dielectric bonding would not be used in the field due to the nature of the equipment required. Extrusion welding is only used with high density polyethylene.

A summary of available membrane seaming methods is presented on Table 4.1

TABLE 4.1

METHODS OF CONSTRUCTING AND EVALUATING GEOMEMBRANE SEAMS REFERENCE (13)

(Thermal and Mechanical Methods)

Base polymer of common geomembrane systems	Thermal Methods					Extrusion	
	Hot air		Hot wedge		Dielectric	(Fusion Welding)	Mechanical
	M	F	M	F	M	F	F
Thermoplastics							
Polyvinyl chloride (PVC)	X	X			X		X
Nitrile - PVC (TN-PVC)	X	X			X		X
Ethylene interpolymer alloy (EIA)	X	X					
Crystalline thermoplastics							
Low-density polyethylene (LDPE)	X	X	X	X			X
High-density polyethylene (HDPE)		X	X	X		X	X
Elastomers							
Butyl rubber (IIR)							
Ethylene propylene diene monomer (EPDM)							
Neoprene (polychloroprene)							
Epichlorohydrin rubber (CO)							
Thermoplastic elastomers							
Chlorinated polyethylene (CPE)	X	X			X		
Hypalon (chlorosulfonated polyethylene) (CSPE)	X	X			X		
Thermoplastic EPDM (T-EPDM)	X	X					

NOTE: M = Manufactured or factory seams.
F = Field fabrication

TABLE 4.1 (continued)

(Adhesives and Tapes)

	Solvent		Bodied Solvent		Solvent Adhesive		Contact Adhesive		Vulcanizing Tape/Adhesive		Tapes
	M	F	M	F	M	F	M	F	M	F	F
Thermoplastics											
Polyvinyl chloride (PVC)	X	X			X	X	X	X			X
Nitrile - PVC (TN-PVC)	X	X			X	X	X	X			X
Ethylene interpolymer alloy (EIA)											
Crystalline thermoplastics											
Low-density polyethylene (LDPE)							X	X			X
High-density polyethylene (HDPE)							X	X			X
Elastomers											
Butyl rubber (IIR)							X	X	X	X	
Ethylene propylene diene monomer (EPDM)							X	X			X
Neoprene (polychloroprene)							X	X			
Epichlorohydrin rubber (CO)							X	X			
Thermoplastic elastomers											
Chlorinated polyethylene (CPE)	X	X	X	X	X	X	X	X			X
Hypalon (chlorosulfonated polyethylene) (CSPE)	X	X	X	X	X	X	X	X			X
Thermoplastic EPDM (T-EPDM)							X	X			

NOTE: M = Manufactured or factory seams
F = Field fabrication

Factory seams generally are considered to have higher uniform quality than field-fabricated seams so it is desirable to produce large liner pieces at the factory. There is no standard size for factory fabricated pieces and most producers will provide what the customer requests. As a guide, pieces approaching 1900 square metres of 30 mil materials are produced quite regularly and would weigh about 2000 kilograms.

4.2.5 Reinforcement

Both reinforced and unreinforced polymeric liners are considered in this report. The introduction of reinforcement or scrim to a liner generally improves the shear strength of the liner and therefore would improve its resistance to failure due to shrinkage, creep, tear and puncture. It may also facilitate handling and seaming of the membrane both in the factory and during field installation by improving dimensional stability.

Polyester is now the dominant scrim material, having generally replaced nylon due to its better acid and sunlight resistance.

The principal disadvantages of reinforced liners are lower elongation to rupture, less ability to conform to ground irregularities, less flexibility, increased potential for delamination of calendered sheets and wicking, and greater costs.

There are differing philosophies related to the most desirable liner property to resist imposed stresses. One philosophy suggests the liner should possess high strength as a dominant characteristic while another suggests the liner should have potential for high elongation. The significance of this is discussed in subsequent sections of this report.

Provided the subgrade of the tailings basin is properly prepared so that it is relatively smooth and will not transmit load to the liner due to movement or require it to carry excessive hydrostatic stresses, the liner would probably be subjected to the most significant stresses during installation. Careful planning will be required to minimize handling stress on the liner. It is desirable, however, that the liner possess sufficient tensile strength to permit ease in handling and to resist unavoidable stresses. Further, due to the potential for some polymeric liners to creep, it would probably be desirable to have some reinforcement in liners susceptible to creep when they are placed on slopes.

As noted, reinforced liners may be more susceptible to delamination. It is considered that this is a function of scrim size and spacing. The polymeric sheeting depends on compound strike through to adhere to itself. Heavy, tightly-woven scrims would probably reduce the percentage of strike area and the interply bond may be lessened. In an effort to enhance strike through, some manufacturers use heavier scrim with lower thread count which provides a larger weave opening.

The other potential problem associated with liner reinforcement noted above is wicking. Wicking is a process which causes delamination when the scrim material is exposed to the waste effluent. The scrim strands absorb effluent resulting in trapped effluent between membrane sheets. Delamination results due to the formation of gas bubbles upon evaporation or decomposition of the waste. To prevent this, selvage edges are now provided for the membrane during the calendering process. This is done by terminating the scrim material 12 to 25 millimetres from the liner's edge. The covering of exposed edges in field seaming must also be specified to further protect against wicking. This is especially necessary when the liner must be tailored to fit around internal basin structures and whenever there is a chance of the factory selvage edge being removed.

It may be noted that a scrim is characterized by its count and the linear density of its yarns. The count is the number of yarns per unit width in each direction described as the warp direction and filling direction (machine direction and cross machine direction). Linear density is mass per unit length with the traditional unit being the dernier which is equal to 0.11 milligrams per metre. Examples of common scrims in North America are:

i) 16 x 8/inch; 125 dernier x 250 dernier; lino weave; often called 8 x 8, 250.

ii) 10 x 10/inch; 1000 dernier (both directions); plain weave; often called 10 x 10, 1000.

4.2.6 Quality Control

Based on information collected from and conversations with liner manufacturers there would appear to be large variations in the quality control programmes routinely carried out during factory fabrication of liners. These programmes would vary from visual examination of the membranes during fabrication to detailed testing including:

i) raw material testing to "finger print" the material supplies

ii) continuous visual inspection during film manufacture

iii) physical property determination of random samples from the sheet rolls

iv) visual inspection and testing of all factory seams.

Tests carried out to "finger print" the raw material or verify consistent product quality might include:

i) the melt index (ASTM D1238) which is a numerical qualification of the molecular weight

ii) the density of the material which is an indication of a range of properties including tensile strength, hardness and chemical resistance

iii) moisture content.

Visual inspection is carried out to identify possible contaminants or the presence of pinholes or other defects.

The testing carried out to determine physical properties of random samples might include:

i) thickness determination
ii) carbon content
iii) tensile strength and elongation testing
iv) carbon black content
v) tensile impact testing
vi) stress cracking resistance

It is anticipated that the larger more experienced liner manufacturers would have in effect a more detailed quality control programme including many of the tests outlined above. In any event, following selection of a lining material for a particular installation, a minimum quality control programme during liner fabrication would include the following:

i) "finger printing" of each batch of raw material

ii) independent verification of the chemical composition of each new batch of polymeric compound.

iii) routine and frequent visits to the manufacturer to inspect the testing facilities, factory operations, and factory seaming

iv) certified laboratory test results provided for each day`s production of liner material.

v) continuous testing of all factory seams by a method such as air lancing.

Quality control during liner installation is discussed in Section 7.

4.3 General Characteristics of Liner Types

Various thermoplastics and elastomers have found application as liner materials; nine different materials are considered in this study. The following is a general discussion of the characteristics of the various materials. The discussion considers the base polymer but not the possible effects of varying concentrations and types of additives used by different suppliers and manufacturers during the compounding stage of production. Specific material properties are not discussed in this section but where information is available related to liner permeability, values are quoted. There is significant variation in the values quoted, which may, in part, be due to:

i) difference in polymeric compounds

ii) variable laboratory testing techniques and test fluids

iii) permeabilities which are representative of field conditions but which may not represent the value obtained by testing on intact pieces of liner.

It must be stressed that it is very difficult to carry out accurate permeability testing on polymeric membranes due to their extremely low permeability. Further, it is recognized that the mechanisms by which fluids flow through geomembranes is different from those which govern flow through soil in that Darcy's law does not strictly apply. It is very convenient, however, to describe liner permeability in terms usually reserved for soils. Finally, it is important to note that much of the reported permeability data relates to testing in the presence of a leachate of interest. Where a lining material is not particularly compatible with the leachate, permeability could be significantly higher.

4.3.1 Polyethylene (PE)

Polyethylene is produced by the polymerization of ethylene and is classified as a crystalline thermoplastic. Conventional (low density) polyethylene is produced with high pressure polymerization giving a non-linear chain. Polyethylene does not contain plasticizers to increase flexibility so it is produced by extrusion with thicknesses limited to the 4-12 mil range. Material properties for this class of liner can be modified by various processing techniques producing cross-laminated or pre-stressed lining materials.

The following properties have been noted for polyethylene:

- low initial cost(14)
- low shipping weight(14)
- great resistance to bacteriological deterioration(17)
- good tensile strength(16)
- few restrictions on chemical exposure(16)
- good low temperature characteristics(16)
- embrittled by exposure to ultraviolet light(16)

- poor puncture resistance (17)
- poor abrasion resistance (14)
- poor tear strength (18)
- susceptible to stress cracking (18)
- very stiff to handle, except in thicknesses under 8 mils, especially in sub-freezing conditions (14,18)
- permeability of 1.5×10^{-9} centimetres per second (11)

Polyethylene has a crystalline structure and becomes brittle when exposed to weathering (18). The characteristics of poor weatherability and poor puncture resistance can be offset to some extent by using a soil cover over the liner (16, 19), thus polyethylene liners are not considered for long term and exposed use (8).

Polyethylene can be heat-sealed in the factory, producing good seals between panels. In the field, seams are usually sealed with self-adhesive tapes (15) or cements. These joints have low shear strength and adhesion can deteriorate under continuous liquid immersion (18).

Polyethylene is inert to most solvents (8) and is generally considered to offer fair to good overall hydrocarbon resistance (8, 20, 21. These liners are also relatively inexpensive, however, life expectancy is proportionally shorter relative to the more expensive liner materials. Field splicing appears to be the major drawback of polyethylene and this material must be placed under a soil cover for protection from puncture and weathering.

4.3.2 High Density Polyethylene (HDPE)

Many of the undesirable features of standard polyethylene may be avoided by modifying the material using high density polyethylene polymers and low pressure polymerization to produce linear chains.(22) Like low density polyethylene HDPE does not contain plasticizers; it is extruded in sheet thicknesses of 20 to 100 mils.

The following general properties of HDPE have been noted:

(i) Chemical resistance to hydrocarbons oil, acids and alkalies is superior to that of rubber (butyl and polychloroprene) membranes.(23,24)

(ii) Material may be placed on slopes with the stability of the soil and not that of the liner being the limiting factor.(23,24)

(iii) The material has excellent puncture and tear resistance and personnel and rubber tired vehicles can move freely on the sheet during installation, maintenance, and inspection.(23,24)

(iv) The material offers excellent ultra-violet resistance. Weatherometer testing indicates an unprotected life expectancy of greater than 40 years.(23, 24, 25)

(v) Field welding of seams is by means of fusion or extrusion joining apparatus which extrudes a ribbon of HDPE which is then fused by a roller train; thus, glues, solvents and adhesives are not required.

(vi) Non-destructive quality control of all seams can be carried out by ultrasonic testing methods.

(vii) The lack of plasticizers reduces concerns about microbial attack.(25)

(viii) Superior strength and elongation properties.(22)

(ix) Rated to 200 degrees Fahrenheit continuous exposure.(22)

(x) Rated to -76 degrees Fahrenheit continuous exposure.(22)

(xi) Good resistance to exposure to gamma radiation.(25)

(xii) Permeability reportedly in the order of 1×10^{-13} centimetres per second.(24)

Cost of HDPE may be somewhat higher than the other lining materials being considered. The other negative characteristic of this product is its stiffness, its high coefficient of thermal expansion and its poor dimensional stability, which renders it cumbersome for handling and placing in the field.

Until relatively recently HDPE had limited use in large installations in North America. However. the installation of HDPE for uranium tailings pond liners at the Dawn Uranium Mining facilities in Ford, Washington (11.3 hectares in 1981) and at other large installations such as the Public Service Company of Colorado's Power Station facilities (26.9 hectares in 1979 and 1980), has generated considerable interest in the use of HDPE.

4.3.3 Chlorinated Polyethylene (CPE)

Chlorinated polyethylene (CPE) was introduced commercially in 1965 by Dow Chemical Company for applications between vinyl and butyl and is classified as a thermoplastic elastomer. It is generally specified in thicknesses between 20 and 45 mils. It is an inherently flexible thermoplastic produced by chlorinating high density polyethylene. Compounded CPE sheets commonly contain between 2-5 per cent additives. CPE formulations contain little or no plasticizers(26) but may contain a controlled amount of PVC polymer to aid dimensional stability and processability. Alternatively, these polymers can be reinforced with nylon or polyester(15). CPE is compatible with many other plastics and rubbers while retaining most of its desirable characteristics. It has been successfully blended with polyethylene, PVC, ABS and several synthetic rubbers to improve crack resistance(8).

The following properties have been noted for CPE resins:

- since CPE is a completely saturated polymer (no double bonds) it is not susceptible to ozone attack and it displays excellent weatherability(27, 28)
- because it contains little or no plasticizer CPE has good resistance to growth of mold, mildew, fungus, and bacteria(27, 29, 28)
- non-volatile(29)
- good tensile and elongation strength(16)
- good resistance to ultra-violet light(27, 30)
- serviceable to low temperatures(29)
- excellent crack and impact resistance at low temperature(8)
- good resistance to deterioration by many corrosive and toxic chemicals(28)
- limited range of tolerance for aliphatic hydrocarbons and oils but can be formulated to improve resistance(8, 28)
- tends to swell in oil when immersed, but resultant loss in tensile strength still within suitable working range(21)

- excessive linear swell in highly aromatic hydrocarbons(15)
- low recovery when subjected to tensile stress(18)
- permeability generally reported to be less than 1×10^{-12} centimetres per second
- limited resistance to acids(25)
- requires reinforcement on slopes(25)
- slopes limited to 1.5 horizontal to 1 vertical(11)

The properties of CPE are similar to those of HYPALON (CSPE). Since CPE is generally unvulcanized it can be seamed by adhesives, solvent welding, or dielectric heat sealing.(31) Field joints are commonly solvent welded, often with xylene or a mixture of tetrahydrofuran and toluene. Field joints are difficult to make at temperatures less than 10 degrees Celsius due to the high flash point of the solvent welding solution, in other words early adhesive strength of the jointing surfaces does not develop.(18) The overall integrity of these solvent welded joints has been questioned.(18)

Where there will be no danger of mechanical damage, CPE liners can be used exposed. Samples exposed in Arizona for nearly ten years retained 90 per cent of their tensile and elongation properties, with little or no change in low temperature impact resistance. As an exposed containment membrane, CPE is expected to last more than ten years, based on no mechanical damage.(21)

CPE liners are in the low to medium price range for comparable synthetic liners.(14)

4.3.4 Chlorosulphonated Polyethylene (CSPE)

Chlorosulphonated polyethylene (CSPE) is a family of polymers prepared by reacting polyethylene in solution with chorine and sulphur dioxide. Presently available polymers contain 25-43 per cent chlorine and 1-1.4 per cent sulphur. CSPE is commonly known by the DuPont trade name, HYPALON.

Although the polymer was developed in the early 1940's it did not attain any degree of publicity as a lining material until 1960. In liners, it is used in unvulcanized compounds containing at least 45 per cent of the base resin. Other ingredients are predominantly fillers.

CSPE may be both a plastic and an elastomer, depending on the degree of curing. It is classified as a thermoplastic elastomer.

Most CSPE liner sheeting is made with fabric reinforcement (nylon scrim)(29). After PVC, it is the most common of the polymeric flexible liner materials(29). The minimum and most popular sheet thickness is 30 mil but it is available up to 120 mil thick, either unsupported or scrim supported. The use of unsupported Hypalon is generally not recommended. This is due to it's relatively low strength properties in the uncured state and resulting installation and creep related problems. Sheeting is usually supplied in 1.2-1.5

metre wide semi-cured panels, and can be factory fabricated in up to 1900 square metre panels(32).

CSPE sheets are semi-cured when installed and field curing (vulcanizing process) takes approximately two to three months in relatively warm summer temperatures(33). The following properties have been noted:

- good puncture resistance(16, 29, 34)
- good resistance to microbiological attack(32)
- excellent resistance to low temperature cracking(18)
- superior resistance to gamma radiation(24)
- excellent weather resistance and aging due to slow vulcanizing process(27)
- good resistance to ozone and ultra-violet light(8)
- flexible and resilient, accommodates movement due to settling(32)
- low tensile strength(8, 16) but good recovery of tensile strength(18)
- uncured CSPE is more thermoplastic than other elastomers but after curing it has good dimensional stability at high ambient temperatures(21, 28)

- poor resistance to aromatic hydrocarbons(33)
- permeability generally reported to be of the order of 1 x 10^{-12} centimetres per second in water(25)
- other references indicate permeability of 1 x 10^{-10} centimetres per second(11)

As the material cures in the field, tensile strength increases, elongation decreases and the film becomes less vulnerable to puncture(33). Dimensional stability, creep resistance, and operating temperature are all related; the material will tend to shrink and soften at elevated temperatures(26). CSPE swells in aromatic hydrocarbons(15). Milder hydrocarbons have a less severe effect and in some instances, CSPE shows resistance to certain hydrocarbons. The material will recover if cleaned of hydrocarbons within a few days of contact(34). As the material cures, its hydrocarbon resistance will improve. Higher temperatures, on the other hand, reduce hydrocarbon resistance.

When first introduced, CSPE developed a poor reputation with respect to:

i) pinholes
ii) shrinkage
iii) field joints

Pinhole control has largely been achieved by lamination. Sandwiching a reinforcing fabric between the lamination helps control shrinkage to less than 2 per cent(14).

A commonly supplied membrane is Burke 30 mil supported Hypalon(35) which consists of one layer of supporting scrim between two plies of Hypalon. Burke 45 mil supported Hypalon consists of two layers of supporting scrim between three plies of Hypalon.

One of the limitations of CSPE is the detailed seaming technique which must be followed exactly(11). CSPE can be seamed by adhesives, heat welding or solvent welding(32). The material is commonly sealed in the factory by solvent welding. Prior to installation, the liner should be stored away from ultra-violet light to ensure adhesion during field seaming(32). Field welds with solvent are best made on warm summer days(33) and solvent seals must be applied before the final cure is complete. The solvent contains 6-10 per cent by weight CSPE polymer blended into a solvent adhesive(26). The solvent places the uncured material in suspension and the lost materials are replaced by the CSPE in the adhesive(30). This jointing system is not affected by damp weather(18) and produces a homogeneous seam. CSPE liners have found application for both exposed and unexposed service.

The above discussion addresses CSPE in general. Major suppliers do, however, supply two grades of material often described as standard or potable water grade CSPE and Industrial Grade or low water absorption CSPE. The major distinction is that the industrial grade CSPE would have a much reduced tendency to absorb water (or chemical leachate), and thus would be expected to have significantly better chemical resistance, permeability, strength and elongation characteristics. For the purpose of further discussion, only the properties of industrial grade or low water absorption CSPE will be considered in subsequent sections of this report.

Hypalon liners are in the medium to high price range for comparable synthetic liners.

4.3.5 Polyvinyl Chloride (PVC)

Polyvinyl chloride, classified as a thermoplastic, is a calendered material available in a wide variety of thicknesses, colours, and compositions.

Polyvinyl chloride (PVC) sheets contain 30-50 per cent of one or more plasticizers, 2 per cent stabilizers, and some filler. Thicknesses of 10-30 mil are common, and most PVC films are used as unsupported sheets. PVC can also be fabric reinforced if required. The physical and chemical properties of PVC film are a function of the specific plasticizers used in various compounds(16, 29).

The following properties have been noted:

- poor resistance to ozone and ultraviolet light resulting in cross bonding and increased stiffness but can be improved with proper stabilization(14,27)
- plasticized PVC film is quite resistant to puncture and relatively easy to splice(29)
- high tensile strenth(29)

- hydrocarbon resistance has been reported to be poor to good(8, 20, 21). Laboratory tests(15) show that some compounds tend to harden and shrink on cyclic exposure to hydrocarbons

- very good resistance to mildew and fungus when compounded properly(27)

- higher cost and shipping weight than polyethylene

- moderate gamma radiation exposure results in soft and tacky compound(25)

- reported permeabilites:
  4.3×10^{-9} cm/sec (landfill leachate)(36)
  7.3×10^{-13} cm/sec (20 mil sheet in water)(25)

The principal problems with standard PVC liners are usually caused by the migration of the non-polymeric plasticizers from the base PVC sheet. Migration of the plasticizer results in a hard, brittle liner(18) reducing resistance to cold weather cracking and affecting elognation properties. Extended heat exposure tends to accelerate this plasticizer loss(18) and some plasticizers can be degraded by micro-organisms without proper microbiocide protection(16). PVC films should be installed loosely, as the material tends to shrink with the loss of plasticizer(30).

PVC film generally holds up well in burial tests, however, some films have deteriorated, presumably due to the specific plasticizer(29). Earth cover is recommended to increase the life of the material(30) and reduce volatile plasticizer loss and polymer degradation(29).

Factory joints are commonly heat sealed, while field joints are usually made with a strong solvent(8). Sealing techniques can cause localized loss of plasticizer. One effect of this is degradation of film repairability(14).

Cold weather installation can be a problem with PVC liners(16). Low temperature flexibility and field jointing are potential concerns under these conditions(18).

Standard PVC films are low in cost relative to most other synthetic liners. Field joint integrity over long periods of time and the effects of plasticizer loss on liner properties has been questioned(18).

Where hydrocarbon resistance is required at a particular installation, oil-resistant compounds of polyvinyl chloride are available. Since the Canadian uranium tailings are not expected to have elevated hydrocarbon concentrations, this grade of PVC is not considered in this study.

4.3.6 Ethylene Propylene Diene Monomer (EPDM)

EPDM is a synthetic rubber made from ethylene propylene diene monomer and is classified as an elastomer. Cured EPDM is used to manufacture either unsupported or scrim-supported sheeting in the range of 20 to 60 mil thickness. The most popular sheet thickness is 45 mil, and the most successful applications have been membranes for roofing and road and railway bridge decks(18).

EPDM synthetic liners are primarily designed for contact with potable water (10) and are fabricated from calendered sheets 1 to 1.5 metres wide.

The following properties have been noted for this class of synthetic liner:

- good aging and weathering characteristics (16)
- good low temperature flexibility (16)
- good heat resistance (16)
- superior to butyl rubber for ozone resistance and weathering (1)
- slightly higher rate of water absorption than butyl rubber (1)
- excellent resistance to water vapour transmission (26)
- resistant to mildew, mold, fungus and microbial attack (32, 25)
- low peel and shear strength (18)
- good general chemical resistance (22)
- poor resistance to aromatic hydrocarbons (26)

- slightly less resistant to radiation damage than CSPE(25)

- reported permeabilities:
  - with sanitary landfill leachate 1×10^{-10} centimetres per second(1,36)
  - with water 2.3×10^{-11} centimetres per second(25)

EPDM liners are not recommended for exposure to solvents or hydrocarbons(16). Laboratory tests(15) show swelling in aromatic and other cyclic hydrocarbons.

EPDM sheets are jointed into panels prior to heat curing. Factory fabricated joints are good, but the same jointing process cannot be used for field fabrication(18). Field seaming techniques commonly employ adhesives such as one or two-part cements and gummed tape. It is difficult to develop good peel strength with these field seaming techniques, and field seaming in moist or cold conditions is relatively difficult. Failures in EPDM liners have been reported due to field joints(18). These joints can deteriorate when subject to immersion under liquids for extended periods of time or when subjected to shear stress(18).

EPDM liners are in the medium to high price range for comparable synthetic liners. This coupled with acknowledged poor resistance to aromatic hydrocarbons and difficulties in field splicing, reduces the potential of EPDM liners for many containment applications.

Although the raw polymers of EPDM are more expensive to produce, their unique properties allow them to absorb a large volume of compounding chemicals and thus produce a lower cost finished product when compared to butyl rubber(1).

4.3.7 Butyl Rubber

Although developed during World War II for automobile tubes butyl was not applied to the lining field until 1960. Butyl rubber was the first elastomer to enter the lining field some 15 years after polyvinyl chloride and polyethyhlene plastic materials.

Butyl rubber sheeting is a copolymer containing approximately 97 per cent isobutylene and a minor amount of isoprene. Cured butyl rubber compounds are used to manufacture either unsupported or fabric reinforced sheeting in the range of 20 to 125 mil thicknesses. Some recent compounds contain small amounts of EPDM rubber to improve ozone resistance of the finished sheet.

The following properties have been noted for this class of synthetic liner:

- excellent resistance to water and water vapour permeation(29, 14)
- excellent resistance to ultraviolet light and to ozone(8)
- resistance to mildew and fungus attack(27)

- generally ages well, although some compounds will ozone crack on long exposure(29)
- high tolerance for temperature extremes(8)
- contains low amounts of extractable material(29)
- good tensile and tear strength, good resistance to puncture(27)
- poor resistance to hydrocarbons(15), particularly petroleum solvents, aromatic hydrocarbons and halogenated solvents(8)
- low peel and shear strength(18)
- difficult field joints
- excellent elongation properties(25)
- reported permeabilities:
  1×10^{-10} cm/sec with landfill leachate(36)
  1.1×10^{-11} cm/sec with water(25)

In outdoor water management use, butyl sheeting has shown 20 years of service with no degradation(29). The overall weathering resistance appears to be a function of the specific compounding.

Seaming, particularly field joints, appears to be a problem. Field splicing, particularly in humid weather, has resulted in liner failure(18). The most common problem with field seaming is "fish mouths" which results when one piece of butyl lining is stressed more than the mating piece. Adhesive systems are commonly used to construct butyl liners; both one and two-part adhesives, and gummed tape have been used. Butyl liners are not heat or solvent sealable(27).

Butyl liners are not recommended for the retention of hydrocarbons and solvents(16). Laboratory tests(15) show swelling in aromatic and other cyclic hydrocarbons.

The fact that butyl liners are in the medium to high price range for comparable synthetic liners, coupled with acknowledged difficulties in field splicing reduces the potential of butyl liners for many containment applications.

4.3.8 Polychloroprene (CR)

Polychloroprene, an elastomer, was introduced by DuPont in 1932 as a synthetic material having good resistance to oil, gasoline, heat, light and ozone. It is commonly known by the Dupont trade name neoprene.

The base resin for neoprene sheeting is polychloroprene rubber. Neoprene is available in 20-60 mil cured sheet, either scrim supported or unsupported. The most popular sheet is reinforced 21 mil for many applications.

The following properties have been noted:

- susceptible to damage from acids and strong salt solutions expected in tailings(25)

- poor aging with respect to sunlight exposure particularly when in contact with earth subgrade(14, 25)
- resists attack by soil micro-organisms, mildew and fungus(32)
- overall good resistance to hydrocarbons, but shows some swell in aromatics and other cyclic hydrocarbons(15, 32)
- flexible and elastic over a wide range of temperatures(32)
- with the exception of chlorinated solvents at high temperatures has very good general chemical resistance(22)
- relatively poor strength properties(22)
- radiation resistance is comparable to CSPE(25)
- resists punctures and tearing from abrasive overlays(32)
- not heat or solvent sealable(27)

Weather resistance can be improved with proper compounding. Film colours other than black deteriorate under ultraviolet light, however, the film reportedly provides good ozone resistance(27).

Neoprene is one of the more difficult materials to seam properly(32). A number of cements are recommended, usually two-part systems(30). In field seaming, high temperature and dry weather are required to produce a film tearing bond. Neoprene is difficult to seam in cold weather(32).

Field seaming difficulties, coupled with the fact that neoprene is one of the most expensive synthetic liners,(32) reduce its potential use. Seaming and cost notwithstanding, neoprene is in demand for its hydrocarbon resistance(30).

4.3.9 Polyurethane

There are two types of urethanes which have been suggested for film manufacture: ester and ether based polyurethanes.

Polyurethane liners can be used for oil spill containment,(21) being one of the toughest and most durable liner materials available(27). However, these liners are considered to be premium priced(27). As a class, the urethanes offer outstanding chemical and oil resistance and excellent low temperature flexibility(27). The specific properties of the two basic types are:

Ester Polyurethane

- fair to good resistance to ozone and ultraviolet light(27)
- good resistance to mildew and fungus attack when properly stabilized(27)

- somewhat superior in hydrocarbon resistance than the ether based resins(21)

Ether Polyurethane

- good resistance to ozone and ultraviolet light(27)

- good resistance to mildew and fungus attack(21)

The main factor affecting all urethanes is hydrolysis;(21) that is, their tendency to break down over long periods of time.

Temperature tends to affect the life expectancy of urethanes, particularly when used as an exposed membrane. Estimates have been suggested for the life span of ester polyurethanes assuming no mechanical damage(21).

Exposed Service -	3-4 years at 20-30 degrees Celsius ambient temperature; 5 years at 10 degrees Celsius ambient temperature
Buried Service -	20 years plus in the absence of alkaline soil, fungus and other micro-organisms

The critical factors for urethane sheeting are humid aging, soil alkalinity, and microbiological attack(21). The esters have poorer tensile strength retention while the ethers have poorer resistance to hydrocarbons(21).

Urethane seaming can be accomplished by heat, cement, and solvents.(27). The adhesive systems in use are similar to those used for CSPE and involve the use of bodied solvents (solvents containing dissolved urethane)(30).

Sheet thickness is usually limited to approximately 18 mil due to cost considerations(30). Conditional on the various drawbacks discussed above, urethane liners offer limited containment application. The prime disadvantages are cost and the long term effects of hydrolysis, soil alkalinity and possibly microbiological attack.

4.4 Liner Material Specifications

Liner materials must be controlled and specified. However, considering the variety of applications for polymeric liners it is not surprising that there are no universally acknowledged testing and acceptance procedures.

Specifications have been both developed and adopted by manufacturers and fabricators. The specifications have come out of the rubber, plastic and textile technologies and have varied considerably. Some of the organizations which have prepared specifications for lining materials are:

(i) American Society for Testing and Materials (ASTM)
(ii) American Society of Civil Engineers (ASCE)
(iii) American Society of Agricultural Engineers (ASAE)
(iv) American Water Works Association(AWWA)
(v) National Sanitation Foundation (NSF)

(vi) United States Bureau of Reclamation (USBR)

Specifications usually involve a number of standard tests performed on polymeric liners in order to assess their mechanical properties. The mechanical property tests are usually performed in accordance with standardized procedures; often ASTM methods. These tests serve to produce comparative information on various liner products and to provide information which allows speculation on installed characteristics.

Problems in comparing liner characteristics arise, as will be seen later in this section, when comparing test results. Similar but not identical testing is carried out for the different liner types. However, there appears to be some relatively recent attempts at standardizing tests and test procedures at least among the various resin classes (ie. thermoplastics, thermoplastic elastomers, etc.).

Further, as noted above, laboratory test results allow speculation on installed liner characteristics or anticipated performance but generally cannot be readily used to predict performance and therefore should not be used as a substitute for good engineering design. In addition, these standardized tests do not take into account the effects of the waste materials on the liner properties. This, of course, is of prime concern in the design of any facility.

An example of the potential inapplicability of comparing laboratory test results to field performance may be noted. Laboratory tests carried out by others(37) indicated that the lowest temperature for field seaming oil resistant PVC with adhesive was approximately 10 degrees Celsius, and the material remained ductile above -18 degrees Celsius. However, in the field, brittle fracture was noted at temperatures as high as 5 degrees Celsius. The anomoly was attributed to increased strain rates and problems associated with scale of laboratory test specimens relative to actual liner size and the effects on properties. Another example would involve testing for dimensional stability (ASTM D1204) usually carried out for periods between 15 minutes and 7 days. This type of testing may be helpful in comparing products (where the tests are identical) but may be of little benefit in the absolute assessment of a product's dimensional stability over a lifetime of several decades or scores of years.

With respect to pond design for tailings basins, considerable significance is placed on the tensile properties and in particular tensile strength and elongation at yield or break. While these properties are considered significant, they may not be particularly relevant if the effect of the liner environment including waste properties is not taken into account by compatibility testing. Further, with respect to tensile strength, it may be noted that where a liner material is covered by soil or tailings it is doubtful whether any liner could resist major stresses associated with loss of support or substantial movement. In addition, while deformations or settlements of tailings basin subgrade or dam structures may be estimated at the design stage, it is extremely difficult to determine the area of lining affected or, in other words, the lined area over which to distribute deformation. This information is required for comparison with the theoretical elongation properties. The analytical problems are largely due to the complex mechanisms at play and in particular the effects of shear resistance of the material overlying and underlying the liner which would tend to limit the ability of liners to strain over large areas.

The above discussion not withstanding, it is considered that standards which provide minimum recommended materials properties are important for a number of reasons, including the following:

i) they provide a rational basis for design in that it may be said at some point in the future that a liner material with certain properties did or did not perform adequately in a particular environment.

ii) specifications are required for quality control to ensure the supply of materials of known and consistent quality.

iii) some material properties such as tensile strength and dimensional stability will be significant during construction.

The most comprehensive document available which deals with polymeric membranes is the recently produced specification by National Sanitation Foundation (NSF) entitled "Standard Number 54, Flexible Membrane Liners"(38). The NSF standard provides recommended minimum material properties for most polymeric membranes including all of the polymeric materials considered in this study with the exception of polyurethane. The NSF recommended test methods and minimum test values and material properties are organized according to resin class and are reproduced in Appendix B. The material properties and test methods for the various resin classes are summarized on Tables 4.2 to 4.5, at the end of this section of the report. This permits ready comparison among the resin classes but not between resin classes (ie. CPE may be easily compared with CSPE but not with HDPE).

A brief description and the significance of the polymeric material properties selected by the NSF for consideration follows:

1. Minimum Specific Gravity

   Specific gravity is often specified for polyethylenes to distinguish between high, medium and low density grades. For other liner materials, specific gravity is not a meaningful property.

2. Tensile Properties

   Ultimate tensile strength, modulus and elongation (and sometimes yield strength and yield elongation) are specified. One of the more important properties of the liner is its ultimate elongation - the ability to stretch before failing. Breaking strength and stiffness (modulus) are more important during installation.

3. Tear Strength

   Tear strength describes the ease with which the cut propagates through the material. Liners with low tear strength values, when containing small cuts or imperfections will have a tendency to propagate the tear more than those with higher tear strength values.

4. Low Temperature Resistance

This test establishes a temperature at which material changes from rubbery to brittle. The results are useful in comparing membranes which are exposed and subjected to low temperatures.

5. Dimensional Stability

Dimensional stability is measured as a percentage of dimensional change due to the exposure of the test specimens at elevated temperatures. Dimensional change is usually due to the stresses built into the liner in the production process. The test is run at the elevated temperature so that the results are obtained in a reasonable time. The same dimensional change is expected to take place at much lower temperatures but at considerably longer time.

6. Volatile Loss

This test measures weight loss of the sample when subjected to elevated temperatures. The test results represent the resistance of the material to the loss of some of the more volatile components, such as plasticizers. Loss of the plasticizer may result in embrittlement of the membrane.

7. Resistance to Soil Burial

In this test, decrease of mechanical properties (tensile strength, elongation and stiffness) of the liner material buried in soil is evaluated. Because of its contact with soil, the liner should have good resistance to soil burial.

8. Hydrostatic Resistance

This test measures resistance of unsupported sheet to hydrostatic pressure. The results of the test have little meaning for the field application.

9. Hardness

Hardness by itself does not correlate with any aspect of the field application. Usually stiffer materials are also harder.

10. Water Resistance and Water Extraction

The water extraction test evaluates extraction of various components of a liner by water. Water absorption measures the degree to which water is absorbed by the liner. Porous materials show high water absorption.

11. Oil Resistance

NSF specifies this test only for selected liners. It measures swelling and change of properties of the liners subjected to oil.

12. Ozone Resistance

This test measures resistance of stressed elastomer to ozone. Ozone resistance is important for the exposed portion of the liner.

13. Environmental Stress Cracking

Polyethylene, when in the stressed condition, is susceptible to environmental stress cracking - cracking caused by various substances, to which polyethylene is exposed. Some substances present in the tailings leachate may cause stress cracking of the liner. Low density polyethylene has better stress cracking resistance than the high density one.

14. Heat Aging

Degradation of properties at elevated temperature is measured. The rationale probably is that the material with poor heat aging properties will also degrade quickly at lower temperatures. Liner exposed to sunlight during a sunny summer day may also be the subject of heat aging.

15. Ply Adhesion

Some of the laminated liners are tested for ply adhesion. Liners with good ply adhesion are expected to be less susceptible to delamination.

16. Factory Seam Strength

The NSF standard specifies testing of seam strength, peel adhesion and resistance to soil burial of factory seams. These tests are meant to ensure soundness of factory seams.

The NSF standards form a good basis for preliminary evaluation of material properties and for some comparisons between liner materials. There are problems comparing existing published test results for lining materials. As an example, a representative summary of liner properties extracted from reference material(25) is presented on Table 4.6. It may be noted that the same test procedures were used for all liner types and resin classes while the recommended NSF test methods are different for the various resin classes. By referring to the material properties and test methods summarized on Table 4.6 and the recommended NSF standards on Tables 4.2 to 4.5 and in Appendix B, it may be noted that for most properties direct comparisons cannot be made. With two exceptions, the material properties provided by liner manufacturers and suppliers in response to the Manufacturer Questionnaire proposed for this study generally do not follow the NSF standards. These two exceptions are the High Density Polyethylene specifications provided by Gundle Lining Systems and the specifications for J.P. Stevens & Co. Inc. 60 mil Industrial Grade Hypalon presented on Tables 4.7 and 4.8, respectively. By comparing the properties addressed and test methods utilized in these specifications with those recommended in the NSF standards it can be seen that most but not all properties can be compared to the standard. The NSF standards are reproduced in detail in Appendix B and the material specifications provided by manufacturers are summarized in Appendix D.

The reasons for variations between published material properties, specifications provided by the manufacturers and available standards such as the NSF publication are associated with the lack of a universally accepted standard. Although the NSF publication is a relatively new document, there appears to be some movement by the liner industry towards standardization of specifications according to this publication and there may be more widespread conformance to it in the future. Accordingly, given that it appears to be a reasonably comprehensive document, it is recommended that the NSF standard should be used and that suppliers of materials considered for use at a prospective installation be required to provide material properties in accordance with the NSF standard. Final material specifications would typically be based on the compatibility and accelerated testing carried out in the liner evaluation segment of project design.

TABLE 4.2

NSF Recommended Test Methods
THERMOPLASTICS (Example: PVC)

PROPERTY	TEST METHOD
Gauge	-
Thickness (mils, minimum)	ASTM D1593 Para. 8.1.3
Specific Gravity (minimum)	ASTM D792 Method A
Minimum Tensile Properties	ASTM D882
1. Breaking factor (pounds/inch width) (N/25mm width)	Method A or B 1 inch width
2. Elongation at Break (per cent)	Method A or B
3. Modulus (force) at 100% Elongation (pounds/inch width) (N/25mm width)	Method A or B
Tear Resistance (pounds, minimum) (N, minimum)	ASTM D1004 Die C
Dimensional Stability (each direction, per cent change maximum)	ASTM D1204 212°F, 15 min.
Water Extraction (per cent loss maximum)	ASTM D3083 (as modified in Appendix B)
Volatile Loss (per cent loss maximum)	ASTM D1203 Method A

TABLE 4.2 (Continued)

PROPERTY	TEST METHOD
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 (as modified in Appendix B)
1. Breaking Factor 2. Elongation at Break 3. Modulus at 100% Elongation	
Hydrostatic Resistance (psi,min.) (MPa, minimum)	ASTM D751 Method A
Factory Seam Requirements	
Bonded Seam Strength (breaking factors pounds per inch width) (N/25mm)	ASTM D3083 (as modified in Appendix B)
Peel Adhesion (pounds/inch, minimum) (N/25mm, minimum)	ASTM D413 (as modified in Appendix B)
Resistance to Soil Burial (per cent change maximum in original value):	ASTM D3083 (as modified in Appendix B)
1. Peel Adhesion 2. Bonded Seam Strength	

TABLE 4.3

NSF Recommended Test Methods
Crystalline Thermoplastics (Example: HDPE)

PROPERTY	TEST METHOD
Gauge	-
Thickness (mils, minimum)	ASTM D1593 para. 8.1.3
Minimum Tensile Properties (each direction):	ASTM D638
1. Tensile strength yield (lb/in width)(N/25mm width)	
2. Tensile Strength at Break (lb/in width) (N/25mm width)	
3. Elongation at yield (per cent)	
4. Elongation at Break (per cent)	
5. Modulus of Elasticity (psi min)(MPa)	
Tear Resistance (lb, minimum) (N, minimum)	ASTM D1004 Die C
Low Temperature, (°F)(°C)	ASTM D746 Procedure B
Dimensional Stability (each direction, per cent change, maximum)	ASTM D1204 212°F, 15 min
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 (as modified in Appendix B)
1. Tensile strength at yield 2. Tensile strength at break 3. Elongation at yield 4. Elgonation at break 5. Modulus of Elasticity	
Environmental Stress Crack (minimum, hours)	ASTM D1593 (as modified in Appendix B)

TABLE 4.3 (Continued)

Factory and Field Seam Requirements

Bonded Seam Strength (factory seam, breaking factor) (pounds per inch width)(N/25mm)	ASTM D3083 (as modified in Appendix B)
Peel Adhesion (pounds/in minimum)(N/25mm minimum)	ASTM D413 (as modified in Appendix B)
Dead Load	
Room Temperature 73°F 50% bonded seam load	See Appendix B
Elevated Temperature 158°F 25% bonded seam load	See Appendix B
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 (as modified in Appendix B)
1. Peel adhesion	
2. Bonded seam strength	

TABLE 4.4

NSF RECOMMENDED TEST METHODS

Supported Thermoplastic Elastomers (Examples: CPE, CSPE)

PROPERTY	TEST METHOD
Gauge	-
Thickness (mils, minimum) 1. Overall 2. Over scrim	ASTM D751
Breaking Strength (pounds, minimum) (N, minimum)	ASTM D751
Tear Strength (pounds, minimum) (N, minimum) 1. Initial 2. After aging	ASTM D751 (as modified in Appendix B)
Low Temperature (°F) (°C)	ASTM D2136 1/8 in. mandrel 4 hrs. pass
Dimensional Stability (each direction, per cent change)	ASTM D1204 212°F, 1 hr.
Volatile Loss (per cent loss maximum)	ASTM D1203 Method A 30 mil sheet
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 30 mil sheet (as modified in Appendix B)
a) Unsupported Sheet 1. Breaking strength 2. Elongation at break 3. Modulus at 100% elongation	

TABLE 4.4 (Continued)

PROPERTY	TEST METHOD
b) Membrane Fabric Breaking Strength	ASTM D751 Method A
Hydrostatic Resistance (psi, minimum)(MPa)	ASTM D751 Method A, Proc. 1
Ply Adhesion (each direction, pounds per inch width, minimum) (N/25mm)	ASTM D413 Machine Method Type A
*Water Absorption (30 per cent weight gain maximum 30 mil unsupported sheet)	
Factory Seam Requirements	
Bonded Seam Strength factory seam; breaking stregnth; lbs., minimum) (N, min.)	ASTM D751 (as modified in Appendix B)
Peel Adhesion (lb./in., minimum) (N/25mm)	ASTM D413 (as modified in Appendix B)
Resistance to Soil Burial (per cent change maximum in original value) 1. Peel Adhesion 2. Bonded Seam Strength	ASTM D3083 (as modified in Appenidix B)

*For raw water (industrial grade) CSPE

TABLE 4.5

NSF RECOMMENDED TEST METHODS

Elastomers (Examples: EPDM, Butyl, Neoprene)

PROPERTY	TEST METHOD
Gauge	-
Thickness (mils, minimum)	ASTM D412
Specific Gravity	ASTM D792
Minimum Tensile Properties (each direction)	ASTM D412
i) Breaking Factor (lbs./inch width)(N/25mm)	
ii) Elongation at Break (%)	
Tear Resistance (lbs., minimum) (N, min.)	ASTM D624 Die C
Low Temperature, (°F)(°C)	ASTM D746 Procedure B
Dimensional Stability (each direction, per cent change maximum)	ASTM D1204 212°F, 7 days
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 (as modified in Appendix B)
1. Breaking Factor	
2. Elongation at Break	
Water Absorption (per cent change, maximum)	ASTM D471 158°F, 168 hrs.
Durometer A Hardness (points)	ASTM D2240 5 second reading

TABLE 4.5 (Continued)

PROPERTY	TEST METHOD
Ozone Resistance	ASTM D1149 7 days, 100 pphm* 104°F, 50% extension
Heat Aging	ASTM D573
1. Elongation (per cent, minimum)	
2. Breaking Factor (lbs./inch width, min.)(N/25mm)	
Factory Seam Requirements	
Bonded Seam Strength (factory seam, breaking factor, lbs./in. width) (N/25mm)	ASTM D3083 (as modified in Appendix B
Peel Adhesion (lbs/in. minimum)	ASTM D413 (as modified in Appendix B)
Dead Load Room temperature 73°F (22.8°C) 50% bonded seam load	See Appendix B
Resistance to Soil Burial (per cent change maximum in original value)	ASTM D3083 (as modified in Appendix B)
Peel Adhesion Bonded seam strength	

*Parts per hundred million

TABLE 4.6

PROPERTIES OF POLYMERIC LINER MEMBRANES INSTALLED AS BARRIERS (REF. 25)

Cell Number	1,19		2,20		3,21		4,22		5,23		6,24	
Liner Number	21		17		7		6		16		12	
Material	Polyethylene		Polyvinyl Chloride		Butyl Rubber		Hypalon, with Nylon Scrim		Ethylene-Propylene-Diene (EPDM) Rubber		Chlorinated Polyethylene	
Thickness, mm (0.0001 in.)	0.25-0.30 (10-12)		0.51-0.53 (20-21)		1.55-1.65 (61-65)		0.81-0.91 (32-36)		1.24-1.35 (49-53)		0.79-0.81 (31-32)	
Coefficient of Water Permeability, cm/s			7.3×10^{-13}		1.1×10^{-11}		3.6×10^{-12}		2.3×10^{-11}		2.0×10^{-12}	
Water Absorption, %												
2 h @ 100°C	-0.61		2.15		0.17		7.17		0.47		2.93	
7 d @ 25°C	0.38		0.95		0.18		2.04		0.61		1.43	
70 d @ 25°C					0.52		4.52		1.90		5.31	
Puncture Test,[a] 25 mm/min,												
maximum force, N (lb)	•				149 (33.5)		131 (29.5)		141 (31.6)		150 (33.8)	
elongation, mm (in.)					29 (1.14)		26 (1.01)		35 (1.38)		26 (1.03)	
Puncture Test, 500 mm/min,												
maximum force, N (lb)	61.9 (13.9)		115 (25.8)		199 (44.8)		146 (32.9)		175 (39.4)		209 (47.0)	
elongation, mm (in.)	19 (0.76)		18 (0.69)		31 (1.22)		15 (0.60)		37 (1.44)		26 (1.04)	
Splice Strength,												
peel, kN/m (lb/in.)	2.73 (15.6)		0.70 (4.0)		0.66 (3.8)		5.25 (30)		0.44 (2.5)		1.75 (10)	
shear, kN/m (lb/in.)	3.54 (20.2)		6.51 (37.2)		5.25 (30)		8.75 (50)		2.56 (14.6)		9.98 (57)	
Hardness, Shore A												
instantaneous	98		81		55		81		57		85	
10 s	98		76		51		79		54		87	
Grain Direction	With	Cross	With	Cross	With	Cross	With	Cross	With	Cross	With	Cross
Modulus @ 100%												
MPa (lb/in.^{2})	8.76 (1270)	7.10 (1030)	8.69 (1260)	7.79 (1130)	2.41 (350)	2.02 (290)	6.90 (1000)	5.93 (860)	2.41 (350)	2.41 (350)	8.41 (1220)	3.59 (520)

TABLE 4.6 Continued

Cell Number	1,19		2,20		3,21		4,22		5,23		6,24	
Liner Number	21		17		7		6		16		12	
Material	Polyethylene		Polyvinyl Chloride		Butyl Rubber		Hypalon, with Nylon Scrim		Ethylene-Propylene-Diene (EPDM) Rubber		Chlorinated Polyethylene	
Modulus @ 200%,												
MPa	10.1	7.24	14.3	12.8	5.31	4.21	11.8	9.17	5.24	5.24	12.5	5.79
(lb/in.^{2})	(1470)	(1050)	(2080)	(1850)	(770)	(610)	(1710)	(1330)	(760)	(760)	(1820)	(840)
Modulus @ 300%,												
MPa	11.6	7.72			8.48	6.90			7.72	7.72	17.0	8.27
(lb/in.^{2})	(1680)	(1120)			(1230)	(1000)			(1120)	(1120)	(2460)	(1200)
Tensile Strength,												
MPa	11.7	17.9	18.2	17.4	9.93	9.86	13.2	11.1	10.4	9.93	17.0	14.3
(lb/in.^{2})	(1700)	(2590)	(2640)	(2520)	(1440)	(1430)	(1920)	(1610)	(1510)	(1440)	(2460)	(2080)
Elongation, %	320	690	270	290	360	430	250	250	420	400	300	520
Set, %	177	667	68	77	15	18	115	106	13	19	199	230
Tear Resistance,$^{(b)}$												
kN/m	72.6	63.0	61.6	55.5	31.5	31.5	56.0	49.0	31.7	31.7	47.2	42.0
(lb/in.)	(415)	(360)	(352)	(317)	(180)	(180)	(320)	(280)	(181)	(181)	(270)	(240)
Creep Test $^{(c)}$												
Load, N	7.78	7.78	14.0	12.7	14.0	12.5	25.3	29.8	8.18	6.89	2.22	14.1
(lb)	(1.75)	(1.75)	(3.15)	(2.85)	(3.14)	(2.82)	(5.68)	(6.7)	(1.84)	(1.55)	(5.0)	(3.18)
• hours to failure	>72 NF	>72 NF	26	12	>94 NF	>94 NF	>96 NF	2.2	>143 NF	>143 NF	31	47
• elongation, %	13.3	47.6	194	138	108	111	194	253	112	102	186	344
• initial stretch, 1 min, %	5.7	7.7	73	51	84	83	15	17	79	78	62	129
• set, %	9.5	19			5.4	5.2		100+	5.6	4.7		176
• creep, cm/cm, 100 h	0.10	0.52	3.88	7.5	0.23	0.23	1.87	99	0.18	0.14	4.5	3.6

(a) Method 2065, Fed. Test Methods 101

(b) ASTM D624, Die C

(c) ASTM D674 - dumbbell specimens, restricted portion 51 mm (2 in.) long by 6.3 mm (0.25 in.) wide.

NF = no failure.

TABLE 4.7

SPECIFICATIONS FOR HIGH DENSITY POLYETHYLENE SUPPLIED BY GUNDLE LINING SYSTEMS LTD.(24)

PROPERTY	TEST METHOD	GAUGE (NOMINAL)					
		0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Density (g/cc) (Minimum)	ASTM D1505	0.94	0.94	0.94	0.94	0.94	0.94
Minimum Tensile Properties (Each direction)	ASTM D638 Type IV Dumb-bell at 2 ipm.						
1. Tensile Strength at Break N/25 cm		356	534	712	1068	1424	1780
2. Tensile Strength at Yield N/25 cm		222	311	422	622	844	1068
3. Elongation at Break (Percent)		700	700	700	700	700	700
4. Elongation at Yield (Percent)		13	13	13	13	13	13
5. Modulus of Elasticity MPA	ASTM D882	760	760	760	760	760	760
Tear Resistance Initiation N	ASTM D1004 Die C	66	98	132	198	264	330
Low Temperature	ASTM D746 Procedure B	−40°C	−40° C	−40°C	−40° C	−40°C	−40° C
Dimensional Stability (Each direction, percent change maximum)	ASTM D1204 212°F 1 hr.	±2	±2	±2	±2	±2	±2
Volatile Loss (Maximum %)	ASTM D1203 Method A	0.1	0.1	0.1	0.1	0.1	0.1
Resistance to Soil Burial (Percent change maximum in original value) Tensile Strength and Elongation at Break and Yield	ASTM D3083 using ASTM D638 Type IV Dumb-bell at 2 ipm.	±10	±10	±10	±10	±10	±10
Ozone Resistance	ASTM D1149 7 days 100 pphm, 104°F. Magnification	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×
Environmental Stress Crack (Minimum hours)	ASTM D1693	750	750	750	750	750	750
Puncture Resistance N	FTMS 101B	378	600	778	1200	1556	1957
Water Absorption (% Weight change)	ASTM D570	0.1	0.1	0.1	0.1	0.1	0.1
Hydrostatic Resistance MPA	ASTM D751 Method A Procedure I	1.1	1.65	2.17	3.38	4.48	5.59

TABLE 4.8

SPECIFICATIONS FOR 60 MIL REINFORCED INDUSTRIAL GRADE HYPALON SUPPLIED BY J.P. STEVENS & CO. INC.(65)

PHYSICAL SPECIFICATION

PROPERTY	TEST METHOD	SPECIFICATION
Gauge (nominal)	--	60
Thickness, mils minimum	ASTM D751	55
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	300
Tear Strength (pounds, minimum)	ASTM D751	90
Low Temperature, °F	ASTM D2136 1/8 in. mandrel 4 hrs., Pass	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	4
Volatile Loss (percent loss maximum	ASTM D1203 Method A 30 mil sheet	0.5
Hydrostatic Resistance (lbs./sq. in. minimum)	ASTM D751 Method A Procedure 1	300
Ply Adhesion (each direction, lbs./in. width minimum)	ASTM D413 Machine Method Type A	8
Water Absorption (percent weight gain maximum-30 mil unsupported sheet)	ASTM D471	
	14 days @ 70°F	1.5
	30 days @ 70°F	2.0
	14 days @ 158°F	30.0
	30 days @ 158°F	30.0

5. ASPHALTIC MEMBRANES

5.1 Introduction

Various asphaltic compositions may be considered for use as tailings basin liners. The compositions are categorized as:

i) sprayed on asphaltic membranes
ii) asphaltic concrete
iii) soil asphalt

By definition asphaltic concrete and soil asphalt are generally not considered to be "thin flexible membranes". Further, due to the costs associated with asphaltic concrete versus polymeric or asphaltic membranes,(25) and due to permeabilities of soil asphalt mixtures (which are reportedly several orders of magnitude higher than most other liner types(25)) only the sprayed on asphaltic membranes will be considered in this study.

Asphalt is obtained either from natural deposits or as a by-product of oil distillation. Asphaltic materials are widely available, are relatively inexpensive and can produce good waterproofing membranes. The relative advantages and disadvantages of asphaltic materials, with respect to their use as liners, are:

Advantages

- stable in the presence of most industrial wastes

- resistant to methyl and ethyl alcohols and glycols

- resistant to most oxidizing acids with the exception of nitric acid(25)

- resistant to mineral salts and alkalies up to concentrations of 30 per cent in solution(25)

- good resistance to corrosive gases such as hydrogen sulphide and sulphur dioxide but may show variable to poor performance when exposed to hydrogen halide vapours(8)

Disadvantages

- susceptible to oxidization by exposure to ultraviolet radiation(25)

- sometimes attacked by microbes if not protected by biocides(25)

- susceptible to subgrade displacement due to poor compaction, freeze/thaw volume changes, and subsidence(25)

- soluble in 5% hydrocarbon solutions(8)

- the thickness of sprayed on asphaltic membranes is difficult to control and may vary significantly from one location to another(12,25)

The use of pure asphalt in membrane form constitutes a most effective construction form from the standpoint of seepage control and cost effectiveness. However, if fully exposed, this form has serious disadvantages in subgrade foundation requirements, weathering and aging because of exposure to solar radiation and heat, erosion from turbulent water, and damage from mechanicanl equipment (39). In order to retain the advantages of a membrane lining while eliminating or minimizing the disadvantages, new types of asphaltic materials were developed involving additives to the basic asphaltic material (8).

Additives which are typically compounded with asphalt include fillers, fibres, and elastomers. Fillers such as limestone, calcium carbonate, clay, fly ash, etc. are added to reduce the basic costs and increase membrane stiffness while fibres such as asbestos or glass fibres may be added to the asphalt to reinforce it (12). Considerable interest has been generated with the use of elastomers such as thermoplastic butadiene-styrene-butadiene copolymer, or reclaimed rubber from tires with asphaltic compounds to improve their mechanical behaviour and resistance to weathering. Elastomers are typically added at between 5 and 15 per cent by weight, (12) but recent developments involve adding about 25 per cent graded rubber particles to asphalt to form an asphalt/rubber mixture (25).

For the purposes of this study asphalt membranes are separated and discussed in three categories, namely:

i) Asphalt Emulsions
ii) Catalytic Airblown Asphalt
iii) Asphaltic Elastomeric Compounds

5.2 Asphalt Emulsions

Asphalt emulsions are dispersions of asphalt in a continuous aqueous phase containing small amounts of emulsifiers. Anionic, cationic and non-ionic grades are available. These emulsions revert to a solid coating by evaporation. To improve toughness and dimensional stability, asphaltic emulsions are generally used in combination with sewed together fabric, glass fibre, or plastic scrims.

Permeability testing carried out on a 7.6 millimetre thick specimen (300 mil) formed by spraying emulsified asphalt at a rate of 2.1 litres per square metre onto a non-woven polypropylene fabric yielded permeabilities of the order of 1×10^{-9} centimetres per second(7).

Asphalt emulsions used to form an asphaltic membrane have several limitations which affect their suitability for long-term service(25). Of primary concern is the relatively small amount of asphalt applied per unit area to form this type of liner. In the event that a hole developed in the asphalt, the fabric would be exposed to potentially damaging materials in which case the very thin asphalt membrane would be required to withstand the tensile and shear stresses imposed by the tailings.

Further, the potential for oxidation with the resulting loss of flexibility and the potential for delamination of the oxidized asphalt from the fabric support is considered to represent a likely failure mechanism(25). Finally, asphalt emulsions must be applied at temperatures above freezing(25).

5.3 Catalytic Airblown Asphalt

Catalytic Airblown Asphalt (also called hot sprayable asphalt) membranes are produced by blowing air at high temperatures through petroleum derived asphalt, in the presence of a phosphorous pentoxide or ferric chloride catalyst. The heated asphalt (minimum 204°C) is sprayed on a stabilized base generally at a minimum application rate of 7 litres per square metre. Repeated applications are necessary to ensure that all pinholes are filled and covered with asphalt. Applications are typically carried out in at least three passes with sufficient overlap of the asphalt distributor between passes and suitable staggering of the joints of each preceding application.

Hot sprayed coatings are flexible, tough materials which are relatively impervious to water. They are usually covered with a soil layer to prevent mechanical damage and light deterioration. However, side slopes steeper than 4 horizontal to 1 vertical are not generally recommended(40). In addition, low temperature ductility is reportedly a concern with this type of asphaltic membrane(25).

In order to evaluate the potential for using catalytic airblown asphalt as a leachate barrier in uranium tailings basins, Pacific Northwest Laboratories carried out accelerated aging testing.(25,41). The test programme also included permeability testing which addressed change of permeability with time of exposure to the uranium tailings leachate. The acid leachate had a pH of between 1.5 and 2.0 and a composition summarized as follows:(25)

CHEMICAL	CONCENTRATION (grams/litre)
$CaSO_4$	500.0
$CaCO_3$	18.1
$MgSO_4$	8.6
Na_2SO_4	7.4
$NaCl$	7.4
Fe_2O_3	2.4
Na_2CO_3	2.3
Al_2O_3	1.2

The catalytic airblown asphalt membrane used in the study was applied in two lifts at an application rate of 6.8 litres per square metre and an application temperature of 205°C. Permeability testing indicated liner permeabilities ranging from 1×10^{-10} centimetres per second to 1×10^{-9} centimetres per second for exposure conditions varying from normal to highly accelerated. Accelerated exposure conditions were simulated by increasing oxygen content and temperature during the exposure period of 90 days. Based on the laboratory testing the catalytic airblown membrane had an anticipated field liner permeability of 7×10^{-9} centimetres per second(25).

The chemical compatability testing carried out on the catalytic airblown asphalt membranes under accelerated conditions indicated a maximum penetration by the leachate of 0.5 per cent of the total liner thickness(41). Based on the results of this testing in which the asphalt was determined to have undergone 7 years of equivalent aging in a 3-month period, it was concluded that the liner could be expected to be effective for at least 1000 years before the entire thickness of the liner would be degraded(41). As noted later in this report, we do not agree with extrapolation by more than one order of magnitude.

Based on the promising results of the laboratory test programme, catalytic airblown asphalt membranes were also subjected to field studies in a pit excavated in an existing uranium tailings pile. It was concluded at the end of the field programme that the asphalt membrane performed effectively as a barrier to leachate flow due to low permeability characteristics. However, one of the three test cells did not perform satisfactorily due to improper application and inspection practices. A one metre square portion of the liner had been applied with insufficient asphalt resulting in holes approximately one centimetre in diameter. This is demonstrative of one of the major concerns associated with sprayed asphalt in that uniform application rates and adequate subgrade coverage are very difficult to achieve and monitor even under the very controlled conditions prevailing.

5.4 Asphaltic/Elastomeric Compounds

Asphaltic materials selected for hot-sprayed membrane application must meet the temperature requirements for application, be flexible at the lowest expected temperature and be sufficiently viscous at the highest expected temperature to resist flowing on sloped sections(42).

The addition of rubber to the asphalt compound reduces the effect of temperature on asphalt viscosity and the elastic properties of rubberized asphalt make this material better suited to accommodating subgrade subsidence, temperature cycling and other conditions expected at tailings disposal sites(25). The rubberized asphalt membranes are generally placed in two or more lifts, as discussed for other sprayed asphalt membranes, to seal pinholes formed by escaping moisture in the first lift. The rubberized asphalt would also be applied at rates similar to other membranes discussed (ie. 7 litres per square metre) and would typically be protected by a layer of soil before heavy equipment is operated on the liner surface(31).

In the past the formulation of rubberized asphalt included the addition of relatively small quantities of rubber (2-3 per cent) to the asphalt to obtain desired temperature-viscosity properties(25). More recently asphalt/rubber admixtures with up to 25 per cent rubber have been developed. The rubber portion often consists of graded rubber particles from discarded tires. The rubber acts as an elastomeric aggregate and allows additional membrane deformation.

Pacific Northwest Laboratories (PNL)(25) conducted accelerated aging tests on membranes formed from asphalt-rubber admixtures under conditions similar to those discussed above for catalytic airblown asphalt liners. The effects of exposure to the acidic simulated uranium tailings leachate were evaluated in terms of effects on liner permeability. The asphalt-rubber mixture contained approximately 79 per cent ASTM Type I roofing asphalt, 19 per cent U.S. Rubber Reclaiming GP274 reclaimed tire rubber, and 2 per cent high-boiling-point asphalt extender oil. The asphalt application rate for this liner type was 5.4 litres per square metre(25). Visual examination of the asphalt-rubber liner following laboratory testing indicated tears at the outer edges of the liner adjacent to the test column. The tears at the edges of the membrane, caused by deflating a subsidence bladder in the exposure column, were believed responsible for an increase in permeability during testing from about 5 x 10^{-8} centimetres per second at the beginning of testing to about 5 x 10^{-6} centimetres per second following about 65 days exposure. A permeability increase was also observed during the testing, following addition of acid to the tailings leachate to reduce pH, and was thought to be indicative of incompatability of the elastomer used in the asphalt-rubber mixture with the highly acidic test conditions(25). Based on the results of the PNL test programme an anticipated field liner permeability of 4 x 10^{-6} centimetres per second was listed for the asphalt-rubber membrane(25).

Research has also been carried out on styrene-butadiene rubber (SBR)/asphalt membranes and their applicability for use in waste disposal seepage control applications for the mining industry in general and the uranium mining and milling industry in particular(43). The materials evaluated were SBR/asphalt blends containing up to 68 per cent asphalt by weight with the balance being elastomeric polymers, fillers and phase compatability promoters. This type of membrane is classified as thermoplastic elastomeric material which is applied by hot spraying. The general properties of SBR/asphalt membranes were noted as follows:(43)

Advantages

- very inert to inorganic acids, bases and salts
- the useful temperature range is extended from -40° to 82°C as compared to 4°C to 49°C for asphalt and the membrane is resilient across the temprature range
- inert to bacteria and fungi
- bonds well to concrete, asphalt, metals, glass and all plastics and rubbers
- good elongation properties (1300 per cent strain at failure)
- excellent resistance to strong acids and bases except strong oxidizing acids such as nitric acid

Disadvantages

- should not be exposed to concentrations of organics
- should not be exposed to direct sunlight for long-term applications
- fair resistance to saturated hydrocarbons

- poor resistance to aromatic hydrocarbons

As a final note, it is anticipated that sprayed-on SBR/asphalt membranes would be subject to the same concerns as the other spray-on asphalts in terms of poor control on rate of application and membrane continuity.

5.5 Material Specifications

The only known specifications in use for the evaluation of asphaltic membranes are those recommended by the Asphalt Institute for hydraulic membrane construction and summarized on Table 5.1. One of the recommended standards, ASTM D-2521, entitled "Tentative Specifications for Asphalt for Use in Waterproof Membrane Construction for Canal, Ditch, or Pond Lining" is reproduced on Table 5.2.

ASTM specification D2521 forms a reasonable basis for evaluating asphaltic membrane materials where bitumen constitutes the majority of the asphaltic compound and only minor amounts of additives are included in the compound.

For the case of asphalt/rubber admixtures and SBR/asphalt membranes discussed in Section 5.4, additional means of controlling and specifying membrane properties are probably required. In this regard consideration may be given to using ASTM D2521 to regulate the asphaltic portion of the compound and a polymeric liner type of specification such as the NSF recommended minimum standards for thermoplastic elastomers for the asphalt/rubber compound; this specification is presented in Appendix B.

TABLE 5.1

SPECIFICATIONS FOR ASPHALT FOR HYDRAULIC MEMBRANE CONSTRUCTION*

Characteristics	AASHO Test Method	ASTM D-2521 Test Method	Grade
Softening Point (Ring and Ball), F	T-53	D-36	175-200
Penetration of Original Sample			
At 32 F, 200 g, 60 sec	T-49	D-5	30+
At 77 F, 100 g, 5 sec			50-60
At 115 F, 50 g, 5 sec			120-
Ductility at 77 F, cm	T-51	D-113	3.5+
Flash Point (Cleveland Open Cup), F	T-48	D-92	425+
Solubility in Carbon Tetrachloride, % @	T44-64I	D-2042	97.0+
Loss on Heating, 325 F, 5 hrs, %	T-47	D-6	1.0-
Penetration after Loss on Heating, % of Original	T-49	D-5	60+
General Requirements	The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated to 400°F. Asphalt should be provided with a satisfactory cover material.		

*Adapted from Reference (39)

#See the Asphalt Institute specifications for asphalt cements and liquid asphalt (SS-2), Reference (44), for latest revisions

@Alternatively, trichloroethylene (not trichloroethane) may be used as the solvent for determining solubility. In the case of dispute, however, carbon tetrachloride will be used as the referee solvent

TABLE 5.2

SPECIFICATIONS FOR ASPHALT USED IN CANAL, DITCH, AND POND LINING

ASTM Designation: D 2521 - 76 (1981)

Softening point (ring and ball)	175 to 200 F (79 to 93 C)
Penetration of original sample:	
at 77 F (25C), 100g, 5 sec.	50 to 60
at 32 F (0C), 200g, 60 sec.	30 min
at 115 F (96.1C), 50g, 5 sec.	120 max
Ductility at 77 F (25 C) cm	3.5 min
Flash point (Cleveland open cup)	425 F (218C) min
Solubility in carbon tetrachloride, per cent	97.0 min
Loss of heating, per cent	1.0 min
Penetration at 77 F (25C) after loss on heating, per cent of original	60 min

6. LINER ENVIRONMENT

6.1 General

A prime goal in the design and operation of uranium mill tailings managements areas is to mitigate adverse effects of tailings leachate on local groundwater. The role of tailings pond liners and tailings dam seepage control barriers is to prevent pollution of the environment due to excessive contaminant migration.

The requirement for a liner is usually based on an evaluation of downstream water quality requirements and not strictly on quantity of seepage. Thus in favourable hydrogeochemical/hydrogeological settings, where the adverse effects of contaminants is offset by geochemical immobilization of contaminants, a higher liner permeability may be allowed. The allowable rate of seepage from the pond would be a function of the nature of the contaminants and the capacity of the native soils, rock and groundwater system for natural purification.

Under favourable geological/hydrogeological conditions a liner may not be required. In extremely sensitive environments where the natural subsurface conditions may not be relied upon to protect the environment, contaminant migration may be reduced to minimum levels by using multiple liners and leachate collection systems. However, even in this case the natural geological setting must be relied upon to control the smaller amounts of contaminants which eventually will escape the collection system. In most cases, including the uranium mining areas presently under consideration, it is anticipated that the solution to the contaminant migration control problem would typically lie between the two extreme conditions described above.

As noted in the above discussion, the major factors controlling seepage from tailings management areas are:

i) site conditions

ii) the characteristics of the tailings (and contaminants) and finally,

iii) the design of the liner system.

These factors are discussed together with uranium tailings management philosophy in the following sections.

6.2 Background

Uranium mining and milling operations have been conducted in Canada since the 1930's. Although the hydrogeology and geology of every existing and potential tailings area is highly site-specific, they tend to be situated in Canada in areas of relatively shallow overburden (Elliot Lake), moderate overburden thickness (Athabasca), and low permeability bedrock.

In 1977, the Atomic Energy Control Board (AECB) proposed draft guidelines in which it was suggested that the average permeability of a tailings basin should not exceed 10^{-5} centimetres per second and that the permeability of containment dams should not exceed 10^{-6} centimetres per second. In the Elliot Lake area, particular site conditions led to the incorporation of synthetic membranes in some containment dams.

These draft guidelines were not finalized. However, in 1980 the AECB produced a consultative document C001 on "Long Term Aspects of Uranium Tailings Management". This document stated that "synthetic membranes which will eventually degrade, will not be credited in the evaluation of a closed-out system". The approval of contaminant control systems in Canada is now given on a site-by-site basis without pre-set objectives which have to be met. However, there is a marked trend towards either reducing seepage losses to low levels or to intercepting seepage for subsequent treatment.

The apparent changes in Canadian attitude towards different categories of liners are, to a large extent, consistent with changes in governmental policy in the USA. Prior to 1982, the Unites States Environmental Protection Agency (USEPA) favoured natural soil (clay) liner systems. However, based on the results of tests which indicated that concentrated organic liquid-bearing wastes altered the structure of clay soils and led to greatly increased permeabilities, the USEPA currently favours synthetic membrane liners to reduce seepage during the operational and early post-closure life of a facility (20 to 30 years) while recognizing that there is very little long term experience with these materials. Indeed, where a site may be used for more than 30 years EPA recommends that since clays last longer than synthetic membranes, a secondary clay liner be incorporated as a back-up should the synthetic membrane deteriorate.

It should be noted that the climatic conditions in much of the USA are very different to those generally prevailing across Canada. In the uranium tailings areas of the southwestern USA, there is net evaporation and it has been generally determined that liners are only required during the active operation of a tailings basin. Following closure, seepage is assumed to be minimal. Such conditions will not apply in Canada, where there is net precipitation at uranium tailings areas.

6.3 Site Considerations

6.3.1 Introduction

The purpose of this section of the report is to discuss site conditions and their effects on the requirements of a seepage control system. The characteristics of sites where artificial lining systems typically would and would not be required are discussed followed by descrptions of typical site conditions in the Elliot Lake-Blind River and southeastern Athabaska regions as well as other areas where uranium mines might be developed.

6.3.2 Site Conditions and the Requirement for Seepage Barriers

The major factors affecting waste management and site selection and the effects of site conditions on the requirements for seepage barriers are:(45)

i) topographical features
ii) climatic factors

iii) hydrological conditions
iv) geological/hydrogeological conditions

Topography is a major factor influencing site suitability and economics. Tailings management areas are ideally situated, in terms of economics, in local topographical lows to take advantage of natural impoundment features and minimize earthworks (dam construction). Disadvantages include the fact that steep hillsides may require large embankments for small impoundment volumes(45). In addition, and also significant, is the fact that topographical lows in northern Canada generally support lake and river systems and contain permeable alluvial strata and/or swampy (muskeg) deposits.

Climatic factors have a major effect on the requirements for long-term management of a tailings area. Precipitation/evaporation characteristics of a site determine the potential for closed system design. In most of Canada there is net precipitation and the tailings area may require an effective cover to prevent a continuous source for leachate and seepage generation. Finally, abandonment of lined facilities involves the requirement for a net precipitation/seepage balance to avoid overtopping or alternatively a permanent excess waste water treatment system.

Hydrological conditions influence site selection in that it would be desirable to avoid stream diversions and lake dewatering where possible. As a guideline, it has been suggested that catchment areas larger than 13 square kilometres (5 square miles) be avoided except where stream diversion can be carried out(45).

Hydrogeological and geological conditions at a prospective tailings management area are the most important considerations affecting the requirement for an artificial lining system or dam seepage barrier. The most significant considerations in evaluating contaminant migration are rate and duration of seepage and contaminant concentration(46). Favourable conditions would include natural soil/rock deposits which have sufficiently low permeability and thickness to retard the flow of contaminants to groundwater and thus allow sufficient time for reductions in contaminant concentrations in the groundwater through dispersion and dilution. Another important consideration would be the ability of native soils and rocks to reduce contaminant migration through geochemical reactions.

Where natural soil/rock strata do not have sufficiently low permeability and thickness to retard seepage and contaminant migration and where the chemistry of the soils and rock do not sufficiently reduce contaminant transport,then artificial means in the form of liners and/or dam seepage barriers are required to control contaminant migration.

6.3.3 Elliot Lake Area

Topography and Climate

The Elliot Lake mining area is located in north-central Ontario. The topography is fairly characteristic of the Canadian Shield and may be described as rugged but of relatively low relief, with elevation differences generally less than 50 metres. Topographic highs consist typically of rock knolls or ridges and topographic lows generally contain swamps, lakes or streams.

The area experiences an average total precipitation of about 950 millimetres per year and the average annual evapotranspiration is about 500 millimetres. Thus, the area is characterized by abundant lakes and streams, with about 20 to 25 per cent of the total area covered by water.

Geology

The uranium deposits in the Elliot Lake area are associated with an approximately 15 kilometre wide sedimentary basin of Precambrian Age which unconformably overlies metavolcanic and metasedimentary basement rocks. The ore occurs in 0.5 to 3 metre thick pyritized quartz pebble conglomerate beds located near the base of the sedimentary sequence and is generally of low grade (0.5 to 1.5 kilograms per tonne).

The various formations within the sedimentary basin (the Quirke Syncline) are largely comprised of quartzite, conglomerate, greywacke, arkose, argillite and minor carbonates. These rocks are generally siliceous in composition and have undergone regional metamorphism such that they contain virtually no intergranular porosity. They attain a thickness of approximately 2,000 metres toward the centre of the syncline and unconformably overlie a granitic and metavolcanic basement complex of Archean Age.

Diabase dykes and sills were intruded into the metasedimentary sequences following the deformation of the basin. The diabase has been dated at about 2100 million years. In addition to the diabase intrusion, various periods of faulting have also occurred within the area including both normal faulting and more structurally complex thrust faulting.

A regional series of steeply dipping normal faults, spaced at intervals of 5 to 7 kilometres, cut the basin in a northwesterly direction. These faults are associated with varying degrees of fracturing and brecciation. Local normal faulting tends to be more intense (2 to 3 features per square kilometre) and, while generally steeply dipping, exhibits variable strike and persistence. In addition to the normal faulting, a major series of thrust faulting occurs along the north and east margins of the basin. The thrusts trend parallel to the strike of the rock strata and are traceable for a distance of 40 to 45 kilometres.

Peneplanation of the rock strata comprising the Huronian Supergroup occurred during the Middle and Late Proterozoic. The resulting land surface has remained little changed to the present time and is characterized by gently rolling, formationally controlled, dip and scarp bedrock ridges. These bedrock ridges vary in elevation by up to 100 metres and control the drainage patterns of lakes and streams within the area.

Glaciation from the last ice age modified and polished the bedrock leaving a very hard, generally smooth, unweathered surface. Unconsolidated glacial deposits are largely restricted to the valleys between the bedrock ridges. These deposits include sandy and silty tills and outwash sands and gravels varying in thickness from less than 3 metres to maximum thicknesses in the order of 30 metres.

Hydrogeology

Groundwater appears to occur as a complex series of local "perched" regimes associated with the lake systems. The majority of groundwater transport between these local regimes occurs through overburden infilled bedrock lows or major discontinuities (e.g. faults) in the rock.

Overburden is restricted to topographic lows and, with the exception of recent bog or swamp deposits, consists predominantly of fluvial or outwash silty sands and gravels of glacial origin. Local deposits of essentially cohesionless silty to sandy till also occur in topographic lows or plastered on the flanks of bedrock highs. The permeability of the till is typically in the order of 10^{-4} to 10^{-5} centimetres per second. The permeability of the granular deposits, particularly the outwash sand and gravel deposits, are considerably higher (in the order of 10^{-3} to 1 centimetre per second).

The bedrock, in comparison to the surficial deposits, is of generally much lower permeability. The permeability of the rock is secondary, related to open jointing and fracture systems within the rock mass. Based on detailed foundation investigations at tailings dams within the area, the permeability of the intact bedrock is in the order of 10^{-3} to 10^{-5} centimetres per second near ground surface but decreases to less than 10^{-5} centimetres per second at a depth of 15 metres below the rock surface. However, fracturing and hence the permeability of the bedrock increases close to features such as faults and dykes, with maximum permeabilities of 5×10^{-3} close to ground surface and permeabilities of 10^{-4} to 10^{-5} centimetres per second at a depth of 15 to 30 metres below the surface of the rock. These features form local preferential zones of groundwater flow within the bedrock. The permeabilities are associated with the degree of openness of the fractures and the higher values tend to be related to near surface weathering (upper 30 metres). However, major fault features of regional extent within the area form deeper conduits for groundwater flow within the bedrock.

The pattern of groundwater flow directions within the bedrock is more complex than that within the surficial deposits due to the nature of the fracture systems. In general terms the flow directions follow the orientation of the structural features from areas of higher elevation to those of lower elevation such as toward discharge zones within valleys or lakes.

Summary

With respect to typical site conditions in the Elliot Lake area, probable sitings for tailings management areas and the requirement for tailings basin liners or synthetic tailings dam seepage barriers, the following general conclusions are drawn:

i) Tailings management areas would be sited in topographical lows or valleys which are probably occupied by lakes or marshy areas.

ii) The valley walls would be comprised, in general, of relatively intact rock with permeabilities in the order of 10^{-3} to 10^{-5} centimetres per second decreasing to less than 10^{-5} centimetres per second at shallow depths.

iii) The valley floors would typically contain a few metres (1-3 metres) of peat overlying up to 30 metres of outwash sand and gravel with permeabilities in the 1×10^{-3} to 1 centimetre per second range and locally of sandy silt till with permeabilities in the 10^{-4} to 10^{-5} centimetres per second range.

iv) Local groundwater flow would typically be from higher elevations to the valleys and therefore in tailings management areas it could be assumed that local groundwater levels are at or above the existing lake or swamp elevations.

v) Saturated flow conditions in materials with relatively high permeabilities (10^{-3} centimetres per second) could be assumed immediately below the bottom of the tailings basin.

vi) Should basin permeabilities of 10^{-5} centimetres per second and dam permeabilities of 10^{-6} centimetres per second or less be made a regulatory requirement then in most areas imported materials for pond liner and dam seepage barrier construction would be required. Previous experience in the Elliot Lake area has indicated that the relatively small amounts of calcium carbonate contained in the outwash sand and gravel do promote co-precipitation and adsorption of radionuclides and heavy metals.

6.3.4 South Eastern Athabasca Region

Topography and Climate

The major belt of uranium mineralization in northern Saskatchewan occurs north of 57 degrees latitude. The surface of the Precambrian rocks has been extensively scoured by glacial erosion and covered with a veneer of glacial and proglacial deposits(47). The topography is characteristic of the Canadian Shield and local relief is generally less than 100 metres(47). Topographical depressions are often infilled with peat. The entire area is within the zone of discontinuous permafrost, and the peat filled depressions often contain ice-rich, permanently frozen ground(47).

Northern Saskatchewan lies in the Boreal or sub-artic climatic region of Canada, typified by extreme temperatures and relatively low precipitation. Meteorological data have been recorded at Cree Lake (57° 22 ' N. Lat. 106° 50 ' W. Long.) since 1970. Extreme temperatures of +35° and -48°C were reported during that period. The mean total precipitation is 460 mm, of which 320 mm fell as rain. The mean annual temperature was -2.8°C. The mean annual freezing index is approximately 3100 C degree days and the mean annual thawing index is approximately 2000 C degree days.(47)

Geology

The uranium deposits of Northern Saskatchewan occur within the Precambrian Shield around the periphery of the Athabasca Formation. Within the eastern half of the region these deposits, including Key Lake, Rabbit Lake and Midwest Lake, occur within areas of relatively subdued topography. Each of the areas is individually discussed in the following paragraphs. Overburden deposits including glacial till and outwash sand and gravel of varying thickness tend to be persistent throughout these areas and bedrock outcropping is limited.

Midwest Lake

The Midwest Lake uranium deposit is located at the south end of the eastern McMahon Lake (renamed Midwest Lake) in Northern Saskatchewan, some 700 kilometres north of Saskatoon.

The uranium ore body roughly follows a north-south trending fault underlying Mink Arm. The topography surrounding this lake is characterized by undulating terrain consisting of drumlins and eskers with numerous lakes and low-lying swampy areas in the intervening depressions.

Surficial materials in the Midwest deposit area consist of ground moraine, till ridges, outwash sand, muskeg and frost-heaved bedrock (felsenmeer). Ground moraine up to 20 metres thick is present south and east of Mink Arm overlying the ore deposit. A long, narrow, north-northeast trending till ridge forms the western boundary of Mink Arm. The ground morraine west of the Mink Arm drumlin is overlain with outwash sand and gravel; an esker ridge is present along the western margin of the outwash sand.

Generally, lakes are present in depressions in the ground morraine and muskeg is present in the low areas around and between the lakes. Deep muskeg in this area may contain permafrost at the base.

The glacial till in the area is silty and sandy, and includes boulders of Athabasca sandstone and basement gneisses. Generally the bulk of the material making up the till is thought to have originated from local preglacial deposits.

The Athabasca sandstone underlying the area is made up of mostly quartz grains and siliceous or argillaceous cement. The usual stratification in the Midwest deposit area, observed in core from top to bottom is given as follows: 110 to 120 metres of massive, jointed, siliceous cemented, medium to coarse sandstone. Some thin stringers of fine to silty sand are present. Between the upper sandstone unit and the basement, the sandstone becomes more argillaceous downward, with numerous pebbly layers. Some thin silty clay and sand stringers are present. The increase in clay content in the lower unit gives the core a rubbly appearance.

The basement rocks underlying the area consist of granite gneisses and metasediments. These rocks are extremely altered and weathered within about 15 metres of the Athabasca sandstone contact. The weathered material (regolith) grades into partially altered fractured gneisses, which grade into fresh rock.

Key Lake

The project area is within the Canadian Shield on the southern fringe of the Athabasca Plains physiographic region. Topographically, the area consists of low elongated ridges separated by shallow depressions containing lakes and muskeg areas. The ridges and lakes are aligned in a northeast-southwest direction which approximately parallels both the bedrock structural trend and the local ice movement direction. The troughs have subsequently been infilled with glacial sands and gravels to form an outwash plain.

The glacial deposits overlying the orebodies extend to a maximum thickness of approximately 85 metres in the deepest part of the trough. To the northeast and southwest, the overburden shallows to approximately 10 to 15 metres at the extremities of the Deilmann and Gaertner ore zones, respectively, marking the boundaries of the glacial trough.

The predominant materials filling the trough are clean outwash sands, which are poorly graded and vary from uniform coarse sand to uniform fine sand to sandy silt, the materials being interlayered throughout the basin. Most of this material appears to have resulted from erosion of the Athabasca Formation.

Immediately overlying the bedrock is a coarse sand, gravel and boulder horizon, which is known to range up to 30 metres in thickness.

The deposits occur near the southern edge of the basin of deposition of the Athabasca sandstone. The lithology of the Athabasca Formation is very uniform and consists of massive, thickly bedded clean quartz sandstone and quartz/quartzite conglomerates, which tend to be concentrated in the lower part of the sequence. Some siltstone may occur locally and cross-bedding is common. The degree of cementation varies considerably, partly as the result of differences in the original lithification. The rock, therefore, varies from very strong to weak. In extreme cases, the rock may be highly weathered and similar to the overlying glacial sand, a feature which has locally caused problems in defining the overburden-bedrock contact.

The basement complex consists of a series of strongly metamorphosed Precambrian rocks of Lower Proterozoic and Archean age. All the rocks have been subjected to folding and subsequent faulting, but show a general, moderate to steep northerly dip in the vicinity of the deposits.

Rabbit Lake

The local surface topography has been formed by differential weathering of the bedrock, by pre and post Athabasca tectonics and by glacial deposits of till, sand and gravel. The regional topography is low with local elevation changes in the order of 75 metres. The morphology is typical of northern Saskatchewan with many small sloughs and muskeg areas, together with stunted tree growth. All, but approximately five per cent, of the bedrock is covered by either glacial deposits or water.

The oldest rocks in the Rabbit Lake area which comprise the basement complex are ancient Archean granites and are more than two billion years old.

Lying on and enfolded into these are the remnants of deformed and recrystallized sediments derived from the Archean rocks. These are called Aphebian and are between 1.7 and 2.0 billion years in age.

About one billion years ago a basin of more or less undisturbed sandstone was laid down on top of the older rocks.

It is at, or near, the interface of the overlying sandstone and underlying rocks that the uranium deposits of northern Saskatchewan occur.

During the deformation of the Aphebian rocks, badly crushed zones were developed by the deforming forces. The Rabbit Lake ore deposit was formed within such a crushed zone. In the central part of the crushed zone, a high grade pitchblende core was present. This was surrounded by an envelope of lower grade mineralization. Thus, an ore deposit was formed of approximately 550 metres in length, 100 metres in width, and 150 metres in depth.

The deposit comes to the present rock surface where it was scraped by the glaciers of about 10,000 years ago. The ice removed the upper part of the orebody and redeposited it within the present soil or overburden, so that economic ore values occur both in the soils and within the rock.

Collins Bay

The surficial deposits and landforms of the Collins Bay area are related directly or indirectly to the last continental glaciation. Several varieties of glacial till cover most of the region although eskers, kames and outwash plains are found. Post glacial deposition occurred in the form of sporadic, fine lacustrine sediments within the larger lakes, and as organic deposition over extensive, poorly drained muskeg areas.

The most apparent influence over the area is the last major glaciation, which had a direction from the north-northeast. Previous to this, older glacial, glaciofluvial, and lacustrine deposits existed. While most of these were removed during the latest glaciation, remnants of till and gravel deposits have been recognized within troughs and protected bedrock valleys.

The tills deposited by the last glaciation are widely distributed and exhibit variable characteristics. Basal till is most common and is generally coarse textured and stony although that which overlies crystalline rocks is finer textured (silty) than that over Athabasca bedrock, which has a corresponding high sand content. A difference in bedrock regimes has also affected the surface and submarine relief features. Drumlins, for instance, are characteristic of those areas lying on top of the Athabasca sandstone. The crystalline bedrock shows less well developed glacial features but the effect of glaciation is still well evidenced. A capping of bouldery, loose, ablation till usually rests on the thick deposits of basal till which may be several yards thick particularly where the Athabasca sandstone contacts other rock groups. Irregular, lake filled and hummocky topography, formed as a result of stagnating glacial ice, is indicative of the presence of those ablation tills.

During the shrinking and retreating of the ice sheet, winding eskers trending north to south and northeast to southwest were formed. They are generally comprised of well to poorly sorted coarse sand and gravel. Outwash plains and deltas developed periodically within or near the esker system. Surface topography within these areas is also quite hummocky. The soil is well drained due to the sorted, loose nature of the underlying material.

The area of the Collins Bay deposit lies within the Churchill Province of the Canadian Shield, on the eastern edge of a broad zone of transition between the predominantly linear Wollaston group of rocks to the east and the Mudjatic group of rocks to the west. These granitoid gneisses typically outcrop as long thin domes surrounded by paragneisses containing variable amounts of graphite.

The Athabasca Formation of Helikian age overlies Aphebian and Archean age rocks in the western part of the area. This Formation consists primarily of quartz sandstones, grits, lesser conglomerates, siltstones and shales.

The conglomerates occurring at the base of the Athabasca Formation are generally underlain by a weathered zone, described as being lateritic in character.

Hydrogeology

Groundwater flow within the Eastern Athabasca region can be subdivided into 4 major components; the surficial glacial deposits, the Athabasca Formation sandstone, the crystalline basement complex and zones of regional faulting.

The surficial deposits of sandy till and outwash sand and gravel within the region are permeable and comprise surficial aquifers. The groundwater flow patterns within these aquifers are largely controlled by local variations in topography, upland regions being areas of recharge and the lakes and streams being areas of discharge.

The Athabasca sandstone comprises a bedrock aquifer of low to moderate permeability (a bulk permeability of about 10^{-4} centimetres per second) that attains a maximum thickness of up to 200 metres within the areas of known mineralization. The permeability is largely insignificant, due to the degree of induration that the rock has undergone.

Groundwater flow within the sandstone is associated with both shallow fresh-water flow systems which are directly influenced by the local topography and deeper flow patterns of regional extent. Such deeper flow patterns are indicated by the occurrence of saline groundwater within the deeper sandstone strata toward the centre of the Athabasca sandstone basin.

Recharge to the sandstone occurs from outcrops or through the overlying surficial deposits, although these vary from permeable sands and gravels to till deposits of significantly lower permeability. Local variations in the bedding and lithological character of the sandstone also influence its permeability.

In contrast to the surficial deposits and sandstone, the crystalline basement complex is of much lower permeability. These rocks tend to form the lower flow boundary of the surficial deposits and sandstone aquifers.

Within the areas of exposed crystalline basement complex beyond the areas of sandstone cover, the upper few metres of the bedrock may tend, in a similar manner to Elliot Lake, to be locally permeable due to the surficial weathering of fractures. The groundwater flow patterns within the sandstone and basement complex are locally intersected by regional faulting, which form linear zones of moderate to high permeability within the bedrock. Because of their fractured nature, such faults are susceptible to weathering and consequently tend to form linear topographic depressions. As such, they are often associated with areas of groundwater discharge commonly occupied by streams and lakes.

Summary

With respect to typical site conditions in the Southeastern Athabasca Region, locations for tailings management areas and the requirement for tailings basin liners and seepage barriers, the following conclusions are noted:

i) Tailings management areas would most likely be situated in topographical lows, which are at present occupied by swamps, marshes and lakes, or in abandoned mines or pits. The topographical lows would typically be broader and would have flatter side slopes than those in the Elliot Lake region.

ii) The valley walls and base would typically be comprised of glacial outwash sands and gravel, coarse grained granular till, and sandstone.

iii) Tailings basin permeabilities may be as low as 10^{-4} centimeters per second locally but would typically be greater than 10^{-3} centimetres per second.

iv) Tailings basins would typically contain peat deposits.

v) Groundwater levels would typically correspond to existing swamps and marshes with groundwater levels somewhat higher in valley walls with net groundwater flow toward the basin.

vi) Basin liners and dam seepage barriers would likely be constructed of imported materials as evidenced by the use of bentonite/soil and polymeric liners in the past and the relatively infrequent occurrence of low permeability soil (clay).

6.3.5 Other Uranium Producing Areas in Canada

Areas favourable for the occurrence of uranium deposits are shown on Figure 2. It may be noted that potential deposits occur in all regions of Canada although deposits are more concentrated in the area north of the Great Lakes, northern Saskatchewan, the Cordillera Region of British Columbia and Alberta and the Northwest Territories. Site conditions, including topography, climate, geology and hydrology vary considerably across the country. However, with the exception of potential deposits in the mountainous Cordillera Region and those located in the upper sub-arctic and arctic regions of permafrost, the comments on tailings management provided for Elliot Lake and northern Saskatchewan would probably also apply, albeit in a general sense.

The development of tailings management areas at potential uranium deposits in areas of permafrost shown on Figure 2 would pose special problems and would provide significantly different conditions than those discussed for the main study areas of Elliot Lake and southeastern Athabasca. These more northern areas would be expected to be low-lying and poorly drained with the topographic lows, which might be otherwise suitable for tailings disposal, often muskeg filled. The more subdued topography could require larger tailings management areas but generally lower dams. All of the problems associated with developing poorly drained sites in the Elliot Lake and southeastern Athabasca Regions would be expected in the arctic or subarctic areas. Added problems of a more harsh climate would be experienced with its effect on liner installation and performance and special engineering problems associated with construction over permafrost.

The construction and performance of pond liners and dams would be expected to be affected by the presence of permafrost in a number of ways including:

i) irregularly, frozen ground would generally not be considered a suitable subgrade upon which to place a liner

ii) once thawed, muskeg and other fine grained frost susceptible soils provide poor foundations for dams and basin liners and would be susceptible to large, differential and generally unpredictable deformations under loading

iii) relative lack of suitable earth borrow materials

If construction is carried out during months where the ground surface remains frozen, then preparation of the subgrade for liner placement would be similar to that required in areas where liners are to be placed over rock. Blasting and levelling of the storage area would be a first step followed by placing a suitable fine grained granular material padding layer for the liner. However, there would be signficant (virtually insurmountable) problems associated with placing and seaming the liner materials during periods when temperatures are permanently at or below 0 degrees Celsius.

Construction during summer months would have to contend with poor site trafficability as well as the requirement that all surficially unfrozen and softened material be removed to provide a suitable subgrade for liner construction.

The added very important problem associated with constructing tailings management areas is the effect of lowering the zone of permafrost and thus thawing the upper soils for at least part of the year by disposing of the tailings in a slurry in an unfrozen state. Most of the soils encountered in these areas with the possible exception of the coarsest of granular materials would be susceptible to drastic loss in shear strength and would be expected to undergo large shear deformations (failure) under the load imposed by the tailings. The liner materials and dam seepage barrier considered in this study, namely flexible geomembranes, would typically not be able to accommodate large shear deformations. The results of large shear deformations is expected to be relatively large scale rupture of basin liners and dam membranes with resulting seepage of leachate into substrata.

Even coarse-grained soils, which would form aquifers beneath a basin in an unfrozen state, could have very low permeabilities in a frozen state(48). Potential seepage and contaminant migration is directly related to the likelihood of tailings thawing the subgrade. Provided the thawed zone did not fully penetrate the permafrost, then leachate migration from the area is unlikely.

Where a geomembrane is considered necessary for tailings management area development in a permafrost environment it is considered that the following are minimum requirements for a successful installation:

i) The management area should be sited in a suitable topographical area comprised largely of material that will not be sensitive to thawing. All unconsolidated materials (overburden and organic matter) could respond drastically to thawing so a rock subgrade is considered desirable.

ii) A suitable fine-grained granular (sand) levelling course should be placed over irregular rock surfaces.

iii) The liner should be installed during summer months and selection of the liner and field seaming methods must take into account the potential temperature extremes and relatively harsh environment.

iv) The requirement for dam construction should be kept to a minimum and should make use of only coarse grained granular material considered relatively non-frost susceptible and which incorporates an embedded geomembrane seepage barrier.

6.4 Characteristics of Uranium Tailings

6.4.1 General

The characteristics of uranium tailings which would impact on liner performance and liner requirements include both physical properties and chemical composition. Significant physical properties of tailings would include:

i) grain size characteristics
ii) bulk unit weight
iii) permeability
iv) water content
v) shear strength

The chemical composition of uranium tailings both at active and inactive tailings management areas is significant due both to present conditions and anticipated changes with time. For the purpose of this study only available information associated with the characteristics of the tailings in the two main uranium producing areas are considered.

6.4.2 Background

Uranium mining and milling operations have been conducted in Canada since the 1930's. Since that time 19 uranium mining operations have produced approximately 119 million tonnes of tailings. Approximately 110 million tonnes have been deposited in a variety of surface impoundment areas covering a total of 635 hectares, with the remainder deposited underwater in lakes or used as mill backfill. The bulk of the uranium mine tailings, 81 per cent (96 million tonnes) are located in the Elliot Lake area of Ontario. Approximately 14 per cent (17 million tonnes) are located in northern Saskatchewan and 5 per cent (6 million tonnes) are located in the Bancroft area of Ontario.

Of the total quantity of tailings, approximately 44 per cent or 52 million tonnes are located in inactive tailings impoundments which no longer receive tailings. The majority of these tailings impoundments were operated from the mid 1950's to the mid 1960's and have been inactive since that time. The remaining 56 per cent or 67 million tonnes of tailings are located in active tailings impoundments which currently receive tailings.

With the exception of the Eldorado Resources Limited Beaverlodge operation which used an alkaline-leach process, all the mine-mill operations use or have used acid -leach process for the extraction of uranium from the ore. At the present time there are four operating mines in Elliot Lake and three in northern Saskatchewan, all using acid-leach process, which produce a total of approximately 8 to 10 million tonnes of tailings per year.

The various active and inactive tailings impoundments in Ontario and northern Saskatchewan vary considerably in character due to differences in size, age, construction of the tailings impoundment and composition of the tailings, as well as regional differences in climate and physiographic setting. These variations make each tailings impoundment relatively unique.

The uranium tailings impoundments in Canada range in size from the small inactive Dyno tailings impoundments at Bancroft which covers 4 hectares and contains only 0.36 million tonnes of tailings, to the active Long Lake tailings impoundment at Elliot Lake which covers 125 hectares and contains 40 million tonnes of tailings. The Nordic tailings impoundment at Elliot Lake is currently the largest inactive tailings impoundment covering 107 hectares and containing 10.9 million tonnes of tailings.

There is also considerable variation in the age of various tailings impoundments. For example, the Dyno tailings impoundment only operated for a short period from 1958 to 1960 whereas the Long Lake tailings impoundment has been in continuous operation since 1959. The Rabbit Lake tailings impoundment in northern Saskatchewan did not begin operations until 1975. The wide ranges in size and age of the uranium tailings impoundments also correspond to differences in the design of the impoundments, the methods of tailings deposition and the types of milling processes at the various sites.

Ore deposits in the Elliot Lake area are large, relatively low-grade deposits with uranium and thorium occurring in brannerite, uraninite and monazite minerals. The principal accessory mineral in the Elliot Lake ores is pyrite (iron sulfide). In contrast, the northern Saskatchewan ore deposits are typically small, high-grade deposits with uranium occurring in pitchblende but with little thorium. Several of the known deposits have substantial quantities of accessory metallic minerals such as gersdorffite (nickel arsenic sulfide) cobaltite (cobalt arsenic sulfide) and millerite (nickel sulfide). These accessory minerals can have a considerable effect on the chemical composition of the tailings.

6.4.3 Physical Properties

For the purpose of this study the information sources selected for the collection of physical properties of uranium tailings from the Elliot Lake and northern Saskatchewan study areas include:

i) Laboratory testing carried out on samples of tailings obtained from Denison Mines' Long Lake impoundment area.

ii) The results of testing carried out on tailings from a tailings test bed which was considered characteristic of tailings to be produced at the Midwest Lake Uranium Mine.(68)

The gradation ranges for coarse (sand) tailings and fine (silt) tailings are shown for the Denison Mines' tailings area and the Midwest Lake test bed tailings on Figures 3 and 4, respectively. Gradation ranges for Midwest Lake tailings are generally located between those of slimes and sand tailings in Elliot Lake.

On Figure 5, natural water contents, total and dry unit weights, in situ vertical effective stresses and undrained shear strength are plotted against depth in the tailings deposit for Denison tailings. From the information noted on Figure 5, the natural water content of the fine tailings decreases noticeably with depth while the coarser tailings demonstrate only a slight decrease in water content. Unit weights and in situ vertical effective stresses tend to increase with depth in a similar fashion for both fine and coarse tailings. Undrained shear strength in the tailings deposit increased with depth to a relatively constant value of about 15 kilopascals below a depth of about 4 metres.

The permeability of the tailings would be governed by void ratio and is controlled by the finer fraction of the whole sample.

Permeability testing was carried out on samples of the silt and sand tailings from the Midwest test and on samples of the silt tailings fraction of the Elliot Lake tailings. The permeability test results indicated that Midwest sand tailings had permeabilities typically in the 5×10^{-6} centimetres per second range for void ratios of between 2 and 4;(68) the Midwest silt tailings had permeabilities typically between 5×10^{-6} and 1×10^{-7} centimetres per second for void ratios between 3 and 6;(68) and the Elliot Lake silt tailings had permeabilities between 1×10^{-5} to 2×10^{-7} centimetres per second for void ratios of between 1 and 2. The coefficient of permeability generally decreased with decreasing void ratio. It was noted that the coefficient of permeability of Midwest sand tailings was less sensitive to variation in void ratio than that of silt tailings; whereas for Elliot Lake tailings the ranges tend to be parallel. Further, the permeability testing indicated that at a given water content (or void ratio) the Midwest tailings appeared to have lower coefficients of permeability than the Elliot Lake tailings.

The coefficient of permeability of granular soil may also be estimated based on grain size distribution characteristics. These estimates are based on the effective grain size of the sample corresponding to the 10 per cent finer than line on the grain size distribution curves. For the grain size distribution curves present on Figures 3 and 4, the following estimates for coefficient of permeability, K, are made:

Midwest Tailings: 3×10^{-4} to 6×10^{-5} cm/sec

Elliot Lake Tailings:

sand tailings: 2×10^{-2} to 5×10^{-5} cm/sec
silt tailings: 3×10^{-4} to 1×10^{-5} cm/sec

These estimated permeabilities are substantially higher than those determined from permeability testing.

Based on the above discussion and the test results presented on Figures 3 to 5, the following is a summary of characteristic properties of uranium tailings considered applicable for this study:

i) in situ water content
   - silt tailings - 60 per cent
   - sand tailings - 30 per cent

ii) total unit weight - 1.8 Mg/m^3

iii) dry unit weight - 1.2 Mg/m^3

iv) undrained shear strength - 15 kilopascals

v) permeability
- silt tailings - 5×10^{-6} cm/sec
- sand tailings - 1×10^{-5} cm/sec

6.4.4 Chemical Properties

The following discussion of the chemical properties of uranium tailings is based on information collected from hydrogeological and hydrogeochemical investigations carried out at active and inactive tailings ponds in the Elliot Lake ara and the results of bench scale milling circuit testing carried out for the Midwest Lake Uranium project (49).

The chemical characteristics of tailings porewater from the Elliot Lake area are presented on Table 6.1 for both neutralized tailings (tailings as discharged from the mill) and oxidized tailings (tailings in storage area which have experienced oxidization.). In Table 6.1 there is a large difference in concentrations of certain elements as well as pH for tailings porewater which has been significantly influenced by iron sulphide (pyrite) oxidation in the tailings.

TABLE 6.1

CHEMICAL CHARACTERISTICS OF TAILINGS POREWATER ELLIOT LAKE AREA

ELEMENT	NEUTRALIZED TAILINGS (mg/l)	OXIDIZED TAILINGS (mg/l)
Total dissolved solids	3,000-5,000	10,000-40,000
Calcium	400-500	400-600
Iron	<1	3,000-15,000
Sulphate	1,000-2,000	5,000-25,000
Chloride	50-100	50-100
Ammonia	50-100	0-100
pH	8-10	2-6
Activity Ra^{226}	600-1,500 pCi/L(50)	10-220 pCi/L(50)

The uranium ore in Elliot Lake is milled using the sulphuric acid-leach process. The tailings liquid is neutralized by lime addition in the mills so that the tailings liquid has a pH of 8 to 10 when the tailings are discharged. The tailings contain about 3 to 7 per cent by weight iron sulphide ($Fe\ S_2$, pyrite). When the discharge of the tailings and the neutralized liquid to the impoundment area ceases and the tailings are exposed to the atmosphere in the unsaturated zone of the tailings, the pyrite reacts with water and oxygen to produce iron and sulphate rich acidic water in the tailings. When the porewater becomes acidic, some radionucluides and heavy metals desorb and dissolve from the tailings causing increased porewater contaminant levels. In areas where the groundwater flow is downward, acidic water produced in the unsaturated zone moves downward replacing the neutralized tailings water and may eventually turn all of the tailings porewater acidic(50).

With respect to radionuclides, it is anticipated that acidic tailings water would have relatively high uranium and thorium concentrations but as shown in Table 6.1, radium (Ra^{226}) shows a tendency to decrease in concentration(50).

The mill effluent final analyses for the Midwest Lake project is presented on Table 6.2(49). Actual concentrations for neutralized or oxidized tailings porewater for northern Saskatchewan are not available. However, the oxidization of the sulphide rich accessory metallic minerals such as gersdorffite, niccolite, cobaltite, pyrite, etc. commonly associated with northern Saskatchewan uranium deposits might be expected to cause sulphate rich acidic tailings porewater in a process similar to that discussed for Elliot Lake tailings, including the anticipated higher levels of some radionuclides and heavy metals in the tailings porewater.

TABLE 6.2

MILL FINAL EFFLUENT ANALYSES
MIDWEST URANIUM PROJECT (REF. 49)

Element	Concentration	Element	Concentration
TSS	< 5 ppm	Bi	<5 ppb
Cl	120 ppm	Cd	<20 ppb
SO_4	3450 ppm	Co	<15 ppb
Mg	13 ppm	Cr	6 ppb
Na	680 ppm	Cu	15 ppb
Ca	720 ppm	Fe	<50 ppb
K	55 ppm	Hg	<10 ppb
PO_4	<10 ppm	Mn	30 ppb
TOC	11 ppm	Ni	45 ppb
Mo	< 0.5 ppm	Pb	60 ppb
Al	< 1 ppm	Se	1 ppb
As	170 ppm	V	20 ppb
B	320 ppm	Zn	<15 ppb
Ba	45 ppm	Total U	<0.5 ppm

Activity:
T.Pb^{210} 1.08 pCi/L
T.Po^{210} 1.08 pCi/L
T.Ra^{226} 0.54 pCi/L
T.Th^{230} <0.27 pCi/L

pH of neutralized tailings = 11

ORGANICS (REF. 51)

Organic	Concentration
Tertiary Amine	2 ppm
Isodecanol	2 ppm
Kerosene (10% aromatic 50% paraffin 40% Naphthene)	25 ppm

It is considered that the tendency for inactive tailings to become increasingly acidic would be a concern in evaluating the long term compatability of geomembranes with uranium tailings. In addition, while radionuclide activities are considered to be relatively low in inactive tailings impoundments, their long term effect would have to be considered.

As shown on Table 6.2, the concentrations of organics are relatively low. Most polymeric and asphaltic membranes will probably not be adversely affected by these very low concentrations but compatibility should be considered.

7. CONTAINMENT FACILITY DESIGN AND LINER INSTALLATION

7.1. General

Site characteristics with respect to liner requirements are addressed in Section 6 of this report.

Uranium mining and milling operations have been conducted in Ontario and Saskatchewan for more than 40 years while undeveloped deposits exist in Newfoundland, British Columbia, Nova Scotia and the Northwest Territories. Obviously, throughout such a large geographic area, wide variations in the hydrogeological setting should be anticipated and design of tailings containment facilities will be highly site specific. However, for the purpose of this report we are assuming a somewhat simplified site geology and hydrogeology consistent with the two uranium producing areas of Canada. Specifically, this section of the report (and Section 11) is based on the following assumptions.

- Low relief Canadian Shield topography.
- Topographic highs consisting of rock knolls and ridges (Elliot Lake).
- Topographic lows consisting of swamps, lakes and streams.
- Siliceous, sedimentary rock overlying basement rocks of complex origin, structure and mineralogy.

- Rock surface is hard, smooth, weathered and relatively permeable. Permeability decreases with depth.

- Overburden in the topographic lows varying from gravel to silty tills.

In addition to topography, geology and hydrogeology, the design of a flexible liner system must also address the many other factors that will substantially influence the ultimate performance of the completed facility. Consideration must be given to capability of contractor, climate, subgrade, preparation, seaming, and quality control. In fact, more than any other factors, the successful performance of the completed liner installation will probably depend on the experience and competence of the fabricator and installation contractor.

The following summarizes the steps outlined in the design and installation of a liner(62). Those relating to earthworks, site preparation, installation, and quality control are discussed further in the balance of this section.

1. Site Selection

2. Geological, Hydrogeological, and Hydrological Investigation and Analysis

3. Engineering Design
   - earthworks
   - compatibility testing

- material selection
- factory and field seam selection

4. Preparation of Fabrication and Panel Layout Drawings

5. Construction
   - access road
   - storage site for materials
   - subgrade preparation
   - earthworks
   - install pipes and other structures
   - fine grade and excavate anchor trench

6. Install Liner
   - inspect surface conditions
   - place sand or geotextile underlay
   - place, unroll and unfold liner panels
   - seam panels together
   - backfill anchor trench
   - seal liner to penetrations
   - install vents and ballast tubes
   - test all field seams; repair if required
   - inspection and acceptance

7. Introduce Tailings into Basin

8. Monitor Leak Detection Systems

7.2 Site Selection

The site selection process for a waste containment facility will consider economic, environmental and engineering criteria. The economic factors associated with land use and cost-benefit analyses are considered beyond the scope of this study. Engineering and environmental factors affecting the site selection should address the following:

1. Identification of major aquifers, aquicludes, recharge areas and sources of groundwater.
2. Groundwater discharge zones.
3. Geological anomalies such as faults, karst terrain, sink holes, etc.
4. Topographical analysis with respect to area hydrogeology.
5. Meterological review with respect to precipitation, temperature extremes, wind, etc.
6. Establish soil and groundwater conditions by means of a subsurface investigation.

7.3 Engineering Design

Compatibility testing, material selection, and seam selection are addressed in Section 8. This section of the report discusses the other major design consideration which is earthworks.

The major item of earthworks required will be based on the type of disposal scheme chosen. Typical of the various site selection options for disposal of mine wastes are:

- valley dams
- ring dykes
- open pit mines
- specially dug pits
- underground mines
- deep lake disposal

The geology, topography, and precedent of the uranium producing areas of Canada is compatible with containment of tailings by valley dams. This and subsequent sections of this report are written on that basis. The design assumptions pertaining to the topography are presented in Section 7.1.

An item of earthworks is the design of an access road to the site. Design of such a road is consistent with conventional design criteria for access roads. This technology is well developed and does not require further discussion in this report.

The other primary element of earthworks design is the dam(s). As has been noted the inferred site geometry will consist of essentially parallel rock ridges containing a valley filled with alluvium, organic deposits and water. Dams will be required at one or both ends of the valley to form a containment area. Dams may also be required to divert creeks and tributaries.

Once borrow areas have been selected, design of zoned embankments (dams) will proceed based on the anticipated strength of the compacted earth materials. Slope stability analyses will be required to select stable design slopes and ensure overall embankment foundation stability.

Other elements of earthworks design are discussed in the pertinent sections relating to construction and liner installation.

7.4 Liner Fabrication

Selection of liner type and seam type constitutes two major design components. The design will also require liner panel layout drawings of a site specific nature in order that the fabricated panels match the site and design components. The primary objective in providing panel layouts is to minimize field seaming and maximize factory seaming.

7.5 Subgrade Preparation

7.5.1 Clearing Grubbing and Stripping

The site should be cleared of all grass, tree stumps, shrubs, brush, tree limbs, roots or other vegetation which could puncture the liner or create methane gas. Such materials should be removed to a disposal site.

Where minor quantities of organic matter, such as 300 millimetres or so of topsoil, are encountered it should be totally removed. However, in the areas considered in this study, considerable quantities of muskeg, peat and other organic materials will be encountered to depths of several metres. Removal of these deposits will prove to be both costly and difficult. Nevertheless, without the benefit of prototype testing, this report assumes that all organic matter will be removed. This assumption is made on the basis that the large total (and possibly differential) settlements associated with compressive (peat) foundations will result in membrane failure. The final decision regarding removal will, in part, be a function of the cost of removal of organic matter as compared to the cost of the prototype testing and the elaborate venting system required if the organic matter remains.

Finally, in comparing liner types, it should be noted that while natural (imported) soil liners or bentonite amended soil liners could not be properly placed over peat or muskeg, there is a chance that synthetic liners might prove satisfactory.

7.5.2 Sterilization of Subgrade

It is very important to remove roots and root contaminated topsoil. However, because it is virtually impossible to remove 100 per cent of all organic matter, the prepared subgrade should be treated with a reliable herbicide. This sterilant should be applied in a uniform manner over the entire site, including the top of the berms; it should be then disked into the soil to a minimum depth of 50 to 100 millimetres and the earth moistened. Application rates should be recommended by the manufacturer with sufficient time allocated between treatment and placement of the liner, to allow the sterilant to penetrate the soil.

7.5.3 Excavation and Filling

If the excavated surface is to receive the liner directly, the area should be thoroughly proofrolled with a minimum 5 tonne smooth-wheeled or pneumatic tire roller. Soft spots should be removed, replaced and compacted. After proofrolling the surface should be blade graded to a surface tolerance of less than 30 millimetres across a 3 metres straight edge. The surface should be smooth, and free from any fractured rock, and no smooth rock should be over 5 millimetres in diameter. If a sand bedding is placed over the excavated surface or if a geotextile underlay is to be installed, the same proofrolling requirement applies.

Fill should be placed in lifts not exceeding about 400 millimetres in thickness. Each lift should be compacted to the recommended percentage of the maximum dry density as determined by the Standard Proctor Moisture-Density Relationship.

7.5.4 Liner Subdrainage and Gas Venting

Liner subdrainage is generally required when it becomes necessary to monitor leakage through the liner system, or to provide pressure relief from a high groundwater table. Situations that necessitate the monitoring of leakage can range from identifying a high valued liquid loss, to a hazardous waste which must be contained. A highly pervious layer of soil or geotextile is placed under the liner providing a predetermined path for the liquid to travel. At various intervals, interceptor subdrains are tied to a main collection header to safely convey the liquid to a collection sump.

Certain site-specific conditions require the venting of gas that may accumulate beneath the liner. If any organic matter exists in the soils under the liner, or if natural gas is present in the region, gas production is inevitable. If the pressure is permitted to increase the membrane can be lifted creating a void for additional gas accumulation and possible overstressing of the liner.

Venting must also be considered when a fluctuating water table is present immediately below the pond bottom. When the water table falls, void spaces in the soil under the liner are created. Air is then sucked into these voids from the surrounding soil. Conversely, when the water table rises, air which was pulled into the voids is displaced upward. The amount of fluctuation and proximity of the water table to the basin bottom, will dictate the reaction of the membrane to this air pumping mechanism.

The need to vent accumulating gas is best accomplished by providing a layer of uniformly graded sand of which less than 5 per cent by weight will pass the 200 sieve. A geotextile may also be used, which allows gas to pass through the fabric's cross-section under a surcharge load.

7.5.5 Finishing

Thorough preparation of the finished surface is a major ingredient in the success of a liner system. In general the surface must provide a firm, unyielding, and smooth foundation, free of dirt, clods, roots, stones, rocks, sticks, sharp objects, or debris of any kind. Two such finished surfaces are geotextile fabric and sand bedding.

Geotextile fabrics are an excellent surface for membrane lined systems. They provide a cushion to protect against abrasive action and significantly reduce the coefficient of friction between the liner and the substrate, increase the evaporation rate of condensation formed beneath the liner, and form a permeable layer to transmit gas while not adhering to the liner.

If no geotextile is used, the finished grade should be a minimum 150 millimetre soil layer, no coarser than poorly graded sand, in accordance with the SP classification of the Uniform Soil Classification System. No stones, rocks or debris of any kind should be within 150 millimetres of the finished surface.

The surface should be graded smooth and compacted to finished elevations in accordance with the recommended tolerances previously indicated.

Particular care will be required around pipes, ducts, and other appurtenances which will protrude through the finished liner.

7.6 Liner Installation

7.6.1 Polymeric Liners

Polymeric liners are fabricated in the factory into a minimum number of pieces to facilitate easy installation. The liner is then packaged, after being accordion folded in both directions, to minimize field handling. Installation of the liner is, in most cases as important to the overall success as material selection. Accordingly, the liner should be installed by a qualified contractor.

Prior to placing the liner, the surface of the impoundment area should be free of projections and debris and graded to properly support the liner. Further discussion on subgrade preparation is contained in Section 7.5 of this report.

For unreinforced liners, side slopes flatter than 3:1 (horizontal to vertical) are generally considered maximum desirable slope angles. Side slopes should be compacted to minimize settlement.

Reinforced liners are recommended for steep side slope applications to improve creep resistance. These scrims will improve puncture resistance, dimensional stability, tear strength and will allow the use of reduced total thickness for the liner. High density polyethylene which is not reinforced and which can be placed on relatively steep slopes is the exception.

Final selection of slope angle should be based on soil/liner interaction and strength tests. Previous testing by Golder Associates indicates that the effective friction angle between sand and one particular membranes was only 20 degrees while the internal friction angle of the sand was greater than 35 degrees. Furthermore, the harder the liner material, the lower the effective friction angle.

The rolled and folded liner panel as delivered to site should be clearly marked on the outside with the panel identification letter or number and the panel size. The panel size is also generally marked on the top fold of the panel inside the carton. Directions for unfolding the panel should be clearly marked on the lid of the container by arrows indicating the direction to "pull" and "spread".

"Pull" - indicates the direction in which the length of the panel is unfolded.

"Spread" - indicates the direction in which the width of the panel is unfolded.

When locating the packaged panels, these markings should be observed so panels can be unfolded in the proper direction. Packaging should be left on the panel until ready to unfold. The panel should not be exposed to direct sunlight but should be completely shaded with opaque sheeting. It is necessary to leave a free-flowing air space between the opaque sheeting and the packaged panel.

When ready to install a sheet, it should be carefully removed from the packaging. Any steel bands should be cut and removed from the general area. The cardboard container should be carefully removed by opening it along stapled edges. Knives should not be used to cut away cardboard siding, lest damage to the liner result. Before the panel is pulled out, any staples on the bottom portion of the carton should be removed and the pallet should be inspected for any protrusions which might cause damage to the panel. Positioning the panel and unfolding it from the pallet is best handled with a large front-end loader or fork lift. The panel is usually double accordion folded with a mass as much as 2000 kilograms.

To pull out the panel, the leading edge is laid on the ground by removing several folds by hand from the top of the panel. By positioning two or three workers on top of the leading edge, the palletized panel can be lifted up with a fork lift truck which can then reverse slowly until the full length of the panel is unfolded. It is helpful to have two men positioned on either side of the palletized panel to walk along and help the folds off the top of the panel as the fork lift backs up.

After the panel is extended to its full length, it is straightened out to the guidelines indicated by the panel layout or the Technical Service Representative. The panel is then spread into position. To achieve this men are positioned along the edge of the panel approximately 5 metres apart depending on the size of the panel and the terrain to be covered. If required, men are positioned at the uphill end of the panel to keep it from sliding down the slope as it is unfolded. If the edge to be gripped is subsequently to be bonded, then the panel edge is folded back about two or three feet, and the fold is gripped for pulling rather than the edge. This is to avoid stretching the edge where it is to be bonded.

Gripping of the panel can be facilitated by use of a short length of dowel, 20 to 40 millimetres in diameter, and 300 to 450 millimetres long. The liner is first wrapped around the dowel, and then gripped. The edges of the dowels should be carefully rounded off to prevent sharp edges from digging into the liner as it is pulled.

As the panel is pulled out it is necessary to maintain air under the liner. This air can be obtained and maintained by several means. One way is to simply hold the edge up and advance at a rate fast enought to capture air underneath as it is unfolded. Another way would be the same as above, except the edge is constantly raised and lowered as it is being spread out to fan air under the liner. When there is a prevailing wind from the direction to which the liner is being pulled, air can be introduced by lifting the edge just enough to allow the required amount of air to blow in under the liner. Care must be exercised in this case to only raise the edge of the liner enough to let the desired amount of air under the liner; it should then be lowered to cut off the air as soon as enough air is captured; otherwise, it is possible to have the liner blow away. A slight lateral tension should be maintained on the leading edge of the panel being spread. This lateral tension facilitates the spreading operations. Panels should be positioned so that succeeding panels to be joined overlap by at least 150 millimetres.

7.6.2 Field Seaming

The liner's strength and sealing ability depends heavily on the quality of the field seams. The field seam quality depends on the installation crew. An inept crew may do a poor job even with the simplest seaming methods.

The necessity of a simple but effective means of constructing field seams may be dramatically illustrated for the case of the example on which costs are based in Section 11. For this example 232 hectares (575 acres) of containment basin would require approximately 300 kilometres (180 miles) of field seams. Considering the dependence of field seaming techniques on a variety of factors, some human, the odds of providing a perfect seal for all 300 kilometres are extremely low.

The three basic requirements for credible field seam production are heat, pressure and dwell time. Job site factors which may influence the field seaming operation include:

i) the ambient temperature and humidity prevailing during which the seams are produced;

ii) wind;

iii) the moisture content of the substrate;

iv) the supporting surface on which the seam is bonded;

v) the skill of the seaming crew;

vi) the qualtiy and consistency of the adhesive;

vii) the cleanliness of the seam interface.

7.6.3 Asphalt Liners

SBR refers to any of a multitude of styrene-butadiene rubbers. By blending thermoplastic SBR polymers with prime grades of asphalt, a thermoplastic material has been developed which behaves as an elastic polymer. The presence of the SBR provides added temperature stability; i.e. flexibility at low temperature and viscosity at high temperatures. This material contains rubber in substantially larger quantities (about 25 per cent) than the more conventional rubberized asphalt. This material looks very promising and is regarded as a variation on asphaltic concrete in which the rubber acts as an elastomeric aggregate. Unlike the normal asphaltic concrete, it would be applied by hot spray application.

Catalytic airblown asphalt membrane(25) is another product which is hot sprayed and requires the use of a catalyst to modify its viscosity properties.

Recommended construction procedures for buried asphalt membranes are summarized as follows:

- Preferred slope inclination 4 horizontal:1 vertical with maximum value of 2 horizontal :1 vertical.
- Sharp objects and rocks should be removed from the foundation soil.
- The foundation soil should be rolled with a smooth steel wheel roller to reduce asphalt demand and soil impregnation.
- In addition to rolling, if the subgrade is dry and dusty, a light sprinkling of water is beneficial.
- Application temperature of 204°C with a slot-type spray bar.
- Multiple passes (minimum of 2) is desirable.
- Recommended application speed of 6.5 kilometres per hour.

7.7 Soil Cover

It is generally accepted that an earth cover over a liner system would be required where the liner is particularly susceptible to exposure to ultra-violet radiation, ozone or other weather related conditions; where there is a potential for mechanical damage due to traffic, animals or vandalism; where there is a potential for damage associated with the placement of the waste materials; and where a long-term service life is required.

According to the manufacturers of the polymeric liners selected for study in this report, most are described as not particularly susceptible to weathering, and exposed use is generally offered as a favourable marketing point. However, essentially all of the polymeric liners are detrimentally affected in varying degress by exposure. It would therefore follow that the provision of an earth cover would extend somewhat the anticipated service life of a given polymeric liner.

The discussion in Section 7.6.1 regarding acceptable slope angles should be considered. Eventually soil/liner interaction and strength testing would be required. For the present, it is recommended that liners intended to receive soil cover should not be placed steeper than 3 horizontal to 1 vertical.

Some asphalts are known to be affected by ultra-violet radiation and both asphaltic concrete and sprayed asphalt may be susceptible to frost action. A soil cover would improve resistance under these conditions. Accordingly, if tailings are not added immediately after application of the membrane, then a soil protection cover at least 300 millimetres thick is recommended.

Polymeric liners and sprayed asphalt membranes are both susceptible to mechanical equipment damage during installation. Further, if the exposed areas will be subjected to traffic during pond operation, a liner cover would minimize the potential for vandalism or accidental damage. Hail and the potential for high wind induced "air-lift" are additional conditions which affect soil cover related decisions.

All liner systems, if exposed, would be susceptible to damage caused by ice movement. Least susceptible would be those liners with higher puncture resistance such as HDPE.

In addition to the above factors, the abrasion related characteristics of the waste material in terms of the potential for damaging a liner system will require investigation.

Based on the above discussion and neglecting costs, a soil cover would appear to be beneficial in that it would probably increase the service life of a liner system and reduce the potential for mechanical damage during basin operation. However, the very operation of placement of a soil cover may itself, significantly increase the chances of puncturing or tearing a liner. Once covered, damage to the liner would probably go unnoticed and thus would not be repaired.

A soil cover should be:

1. Free of sharp stones and not excessively abrasive.

2. Compatible chemically with the contained waste.

3. Stable and resistant to sloughing from wave action.

7.8 Quality Control

Quality control is an inherent and vital part of satisfactory manufacture and fabrication of lining materials. The quality control must continue with the field installation to ensure conformance with the design specifications.

Testing, consistent with conventional civil and geotechnical engineering practice is suitable for the quality control of earthworks relating to embankments, subgrade preparation and soil cover. The primary test procedures would include:

i) Compaction control using volumetric or nuclear density apparatus. With regard to the latter special care will be required to calibrate the equipment for operation in the presence of low level, radioactive wastes.

ii) Straight edge and other survey techniques to confirm line and grade.

iii) Visual monitoring which will probably be the most effective form of quality control. This will be particularly so in ensuring freedom from sharp objects that could rupture the liner.

Visual observation should also be effective in monitoring the condition of asphalt or polymeric membranes. Quality control during the manufacture of polymeric membranes is discussed in Section 4.2.6 of this report. Assuming lining materials are delivered to the site in good condition and visual monitoring confirms that they have not been damaged during installation, then the final item requiring assurance is field welds of polymeric liners. Both destructive and non-destructive test methods should be employed. Depending on the field seaming methods these test procedures might include electronic techniques, air lance testing, vacuum chamber testing, shear and peel testing, test coupons, etc.

Ideally, destructive test methods should be kept to a minimum but should be of sufficient quantity to verify original design specifications. Typically a suitable field seam quality control program would include:

i) Visual inspection of all field seams.

ii) Mechanical testing of daily field seam samples.

iii) Non-destructive testing of all field seams.

Available non-destructive test methods for polymeric membranes and their applicability to the various types of membranes are summarized in Table 7.1.(13)

There are fewer guidelines available for the field evaluation of asphaltic liners. However, daily testing of the asphalt to ensure it conforms with specifications outlined in Section 5 would be required as would routine coupon sampling of placed asphalt to ensure the required thickness is being achieved. Constant and very careful inspection of the asphalt placement procedure would be a prerequisite.

TABLE 7.1

AVAILABLE NON-DESTRUCTIVE TEST METHODS FOR EVALUATING POLYMERIC LINING SEAMS (REF. 13)

	Ultrasonic pulse echo (5-15 MHz)	Ultrasonic impedance (160-185 kHz)	Air lance c/	Vacuum chamber c/	Pressurized dual seam	Electrical sparking	Mechanical point stress
Thermoplastics (PVC)							
Reinforced		X	X	X			X
Nonreinforced	X	X	X	X			X
Crystalline thermoplastics (LDPE; HDPE)							
Nonreinforced	X	X		X	X	X	
Elastomers (Butyl; EPDM; CR)							
Reinforced			X	X			X
Nonreinforced			X	X			X
Thermoplastic elastomers (CPE; Hypalon; EPDM)							
Reinforced		X	X	X			X
Nonreinforced	X	X	X	X			X

A) Vacuum chamber should be restricted to thicknesses of 30 mils and greater due to deformation.

B) Air lance should be restricted to thicknesses less than 45 mils; this method is not recommended for stiff sheeting.

8. PERFORMANCE CRITERIA AND FAILURE MECHANISMS

8.1 Introduction

In previous sections general properties of the polymeric and asphaltic liner materials, anticipated typical liner environment including characteristics of uranium tailings, and the design of containment facility and liner installation have been addressed. In this section of the report the requirements of the liner material under the above noted conditions in terms of performance, compatibility, durability, rate of degradation and release rates are assessed and potential failure mechanisms are discussed.

8.2 Performance Criteria

The primary function of the basin liner system and dam seepage barriers would be to impede the flow of leachate (tailings pore liquid) to a sufficiently low rate to allow the in situ soil/rock groundwater system to accept leachate without adversely affecting groundwater quality. The acceptable seepage rate would be a function of the nature of the contaminants and the capacity of the native soils, rock and groundwater for natural purification through the mechanisms discussed in Section 6.3.1.

Based on the above discussion, the success or failure of a lining system could be evaluated on the basis of whether the lining system released contaminants at or below the design rate over the design life of the tailings impoundment facility. Anticipated release rates are addressed in more detail in Section 10.

During design the liner materials under consideration are usually evaluated, using evaluation criteria discussed above, in terms of the following general requirements:

1. Compatibility and durability of the liner in the presence of the waste to be contained.
2. Reliability and risk of failure (potential failure mechanisms).
3. Relative ease of installation, quality control, repair and maintenance.

Liner installation, quality control, repair and maintenance are addressed in Section 7. Liner compatibility, durability and potential liner failure mechanisms are addressed in the following sections. Rates of liner degradation and the testing associated with liner evaluation are also discussed.

8.3 Liner Compatibility and Durability

8.3.1 General

The compatibility of a liner material in contact with a given waste material, in this case uranium tailings, would typically be evaluated in three stages, namely:

i) Anticipated reactions of the liner to the waste based on available literature and manufacturer's general chemical resistance charts.

ii) A screening test programme in which liners are immersed in waste for fairly short periods of time and possibly at varying temperature to evaluate changes in material properties.

iii) Accelerated testing whereby the liners are evaluated for long term exposure to the waste in laboratory testing which simulates aging of the liners.

A possible fourth stage of liner evaluation would include field testing of a small number of liner types which proved suitable based on the three-staged evaluation noted above. The level of detail associated with liner evaluation provided in this report would correspond to the first of the three stages listed above. Stage II of the study involving the laboratory test programme would correspond to the second and third stages of evaluation listed above.

The major sources of information used in preparing the section of this report addressing liner compatibility include:

1. Previous studies undertaken by Pacific North West Laboratories on Hypalon and asphaltic membranes in the presence of simulated uranium tailings leachate (ref. 25, 54).

2. The results of testing carried out in the presence of uranium mill tailings provided by the suppliers of Hypalon and high density polyethylene.

3. The general chemical resistance information provided by liner suppliers.

4. Generally available chemical resistance of the base polymeric resins to groups or classes of chemicals (ref. 52, 53).

5. The general properties of polymeric and asphaltic liners as discussed and referenced in Sections 4 and 5 of this report.

As noted, the characteristics of the waste material to be contained is of prime importance in evaluating compatibility. In this case the wastes consist of uranium mill tailings with general properties as discussed in Section 6.4. While the characteristics of the tailings will vary from site to site, the general characteristics which are considered particularly relevant include:

i) The lime-treated tailings pond fluid initially has a pH of 10 or 11 and is described as a strong salt solution.

ii) Following oxidation of the sulphide minerals, sulphate rich acidic tailings porewater with a pH of about 2 could be in contact with the liner.

iii) Small concentrations of kerosene will be present in the tailings from northern Saskatchewan. There is also the potential for the presence of large concentrations of kerosene due to accidental spills.

iv) Various radionuclides will be present in the tailings and the liner would therefore be subjected to some radiation.

8.3.2 Polymeric Liners

8.3.2.1 General Chemical Resistance

The resistance of various generic types of polymers to general categories of chemicals are presented in the form of tables throughout the literature. An example of this form of comparison, in tabular form, is presented in Table 8.1. The information presented in Table 8.1 corresponds to base resins and not to the final compounded liner material.

It is important to consider the effects of various additives during the compounding stage of liner manufacture. Excellent resistance to a chemical by a base resin does not guarantee that the final compound will offer the same resistance. In the same vein, if a base resin shows poor resistance to a chemical it is unlikely that compounding would improve resistance. The type of information presented in Table 8.1 would thus form a good starting point in evaluating the various base polymers.

The ratings used in Table 8.1 are explained as follows:

i) Poor (P) - use of the material in the presence of the agent is not recommended The effect varies from catastrophic failure to severe degradation.

ii) Fair (F) - use of the material is marginal.

iii) Good (G) - use of the material is acceptable at room temperature. Long term exposure may result in minor loss of properties, but exposures at elevated temperatures may result in significant property loss.

iv) Excellent (E) - material is unaffected by the agent.

All of the polymeric materials considered in the study, with the exception of polyurethane, are presented in Table 8.1.

Based on the known nature of uranium tailings, the agents listed in Table 8.1 most likely to be in contact with the liner would include diluted inorganic acid, diluted bases and acidic salts. As noted in Table 8.1, all of the liner types considered in this study show excellent resistance to these agents with the exception of Butyl which is rated as good for inorganic acids and diluted bases and polyethylene which is noted as good for diluted bases. With respect to resistance to hydrocarbons, and in particular aromatic hydrocarbons associated with kerosene, all of the liners show poor resistance with the exception of polyethylene which is rated as fair.

It should be noted that the agents considered in the table are at high concentrations. Kerosene in uranium tailings, except in the case of an accidental spill, would be present in very low concentrations and would likely not effect most of the linings at least in the short term.

Similar information to that presented in Table 8.1 has been reviewed for polyurethane(55). Based on the review of the information it has been noted that urethane resin has poor resistance to hydrocarbons; fair to poor resistance to inorganic acids; poor to good resistance to bases; and good to excellent resistance to salts.

Based on the general review of the chemical resistance of the base resins presented above it is concluded that all of the base resins, with the exception of polyurethane, show promise for long-term resistance to uranium tailings. Caution should, however, be noted for Butyl and polyethylene.

TABLE 8.1

GENERAL [illegible]ICAL RESISTANCE OF POLYMERIC LINER MATERIALS (REF. 52, 53)

MATERIAL	AGENT														
	Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Halogenated Hydrocarbons	Alcohols	Ketones	Esters	Diluted Inorganic Acids	Diluted Organic Acids	Diluted Bases	Acidic Salts	Neutral Salts	Basic Salts	Diluted Oxidizing Acids	ASTM #1 Oil	Ozone
Butyl *	P	P	P	G	G	G	G	G	G	E	E	E	F	P	G
Chlorinated Polyethylene *	G	P	P	E	G	G	G	E	E	E	E	E	G	E	E
Chloroprene *	G	P	P	E	F	P	E	P	E	E	E	E	F	E	E
Chlorosulfonated Polyethylene *	G	P	P	E	F	P	E	E	E	E	E	E	G	E	E
Epichlorohydrin	E	P	P	E	F	P	G	F	G	E	E	G	F	E	E
Ethylene Propylene Diene *	P	P	P	G	G	G	E	F	E	E	E	E	F	P	E
Nitrile	G	P	P	E	P	F-P	G	G	F	G	E	G	P	E	D
Polyvinyl Chloride *	G	P	P	G	P	P	E	G	E	E	E	E	E	G	G (weathering)
Polyethylene *	F	F	P	F	G	G	E	E	G	E	E	E	G	E	P (weathering)

NOTE: * - Liner materials considered in study.

General chemical resistance information has also been collected from manufacturers and suppliers of polymeric liners. The companies which responded to the questionnaires and provided general chemical resistance information are included in Appendix D and are summarized below:

Company		Lining Material
Gundle Lining Systems Inc.	-	HDPE
Schlegel Lining Technology Inc.	-	HDPE
Watersaver Company Inc.	-	Industrial Grade Hypalon
	-	CPE
	-	PVC

The Gundle general chemical information would indicate that the Gundle HDPE is generally unaffected by inorganic acids with the exception of chlorosulphuric acid, chromic acid and concentrated sulphuric acid; unaffected by inorganic bases and salts; and generally moderately to severely affected by hydrocarbons. The Schlegel general chemical resistance information indicates that Schlegel HDPE is satisfactory in the presence of most acids with the noticeable exception of concentrated acetic acid, butylic acid, chromic acid, hydroflouric acid, nitric (oxidizing acid) and sulphuric acid (98 per cent concentration); most sulphides with the notable exception of calcium sulphide; and all sulphates tested. Schlegel HDPE would be expected to be affected by most hydrocarbons.

Based on a review of the general chemical resistance data supplied by Watersaver for Hypalon and CPE, the following general comments are made related to chemical resistance evaluated by immersion testing and measuring weight gains after 81 days of testing:

i) Hypalon was relatively unaffected by 3 and 30 per cent solution of sulphuric acid

ii) CPE was affected by the 3 per cent solution of sulphuric acid

iii) Hypalon showed superior resistance to sodium carbonate and sodium chloride.

iv) all are significantly affected by kerosene at 100 per cent concentration

PVC was evaluated by means of immersion testing for 28 days with chemical resistance measured in terms of weight loss. The Watersaver data would indicate that of the chemicals or agents likely to be encountered in tailings, PVC was affected significantly by concentrated sulphuric acid but remained relatively unaffected by a 10 per cent solution of sulphuric acid and concentrated sodium chloride. The other acids used to evaluate PVC in the Watersaver information included acetic, hydrochloric and nitric acids. PVC was affected significantly by concentrated nitric acid.

8.3.2.2 Resistance to Uranium Tailings

Based on a review of literature and conversations with representatives of the liner industry, it is concluded that to date Pacific Northwest Laboratories (PNL) have carried out the most detailed laboratory evaluations of polymeric membranes in the presence of a simulated acidic uranium tailings leachate(25, 54).

A PNL study completed in September 1983 evaluated the performance of a Hypalon sample in an exposure column in which aging was simulated by subjecting the liner sample to increased temperature, elevated oxygen partial pressures and low pH. The Hypalon was evaluated in terms of effect on permeability and the exposure column test results indicated an increase in permeability of from about 6 x 10^{-11} centimetres per second to 2 x 10^{-10} centimetres per second for an exposure time of about 65 days. Oxygen partial pressures during the test varied from 0 to 100 kilopascals, pH varied from 1.8 to 8.0 and test temperatures were held for the most part at slightly above 50°C. The Hypalon demonstrated the lowest permeability and the least change in permeability of the materials tested including asphalt, asphalt/rubber, catalytic asphalt, bentonite, and natural soil.

Additional testing presently underway at PNL includes evaluation of HDPE and PVC membranes in the presence of simulated acidic uranium tailings leachate where pH is held at 2 to 2.5 and controlled by addition of concentrated sulphuric acid(54). To date, exposure periods of up to 29 years have reportedly been simulated by aging the sample in the leachate at 78°C for 18 weeks(54). The liners are being evaluated in terms of thickness, density, tensile strength, elongation, shear strength of seams, and tear resistance. Chemical testing includes differential scanning calorimetry and differential infrared spectrography. The PNL conclusions formed as a result of the testing carried out to date are:(54)

i) Aging reactions were not detected in the HDPE and physical properties were not adversely changed during exposure to the simulated acidic leachate.

ii) Insufficient data was produced to draw conclusions concerning PVC although some chemical changes in the PVC were noted and there was a 19 per cent decrease in the strain measured at failure in the most aged sample. Tensile strength and tear resistance were unaffected, puncture resistance declined significantly and seam strength remained relatively unaffected.

In addition to the test information noted above, some of the liner suppliers/manufacturers provided test data associated with liner compatibility testing in the presence of uranium tailings leachate or "nuclear waste liquid". The results of the testing are presented in Appendix D. The materials tested included industrial grade Hypalon supplied by Watersaver and high density polyethylene supplied by Gundle and Schlegel. A review of the results of the testing supplied by the liner suppliers would indicate that the Hypalon and HDPE tested remained relatively unchanged in the presence of the wastes or that any changes recorded were within acceptable limits. In all cases the evaluations were carried out in terms of changes in physical properties.

8.3.2.3 Resistance to Radiation

In general, polymeric materials are affected by both charged particles and ionizing radiation. Irradiation causes increase of crosslink density of materials resulting in hardening, decrease of the ultimate elongation and, sometimes, increase of tensile strength.

The effect of gamma radiation on physical properties of a number of liners is presented in Table 8.2(25), based on radiation levels thousands of times greater than encountered in uranium tailings. Seven of the liners considered in this study, PVC, HDPE, EPDM, Butyl, Neoprene, CSPE, and CPE, are included in Table 8.2. Based on the information in the table under the exposure conditions noted on the table, the following conclusions are drawn:

i) In terms of the modulus at 200 per cent elongation, Neoprene, HDPE, PVC and EPDM were least affected by gamma radiation. CPE and Hypalon showed the largest increases and butyl the largest decrease in modulus.

ii) In terms of the effect of gamma radiation on tensile strength, EPDM remained relatively unchanged; CPE, Hypalon and HDPE showed increases, Neoprene and PVC showed decreases as did Butyl, which also tended to deteriorate.

iii) In terms of the effects on elongation, EPDM Neoprene and HDPE were the least affected, while Hypalon, Butyl, PVC, and CPE reduced elongation in descending order. However, at higher exposures Butyl tended to degrade while the others generally did not.

iv) Overall, it is considered that HDPE demonstrated the least adverse affects, followed closely by Hypalon and EPDM. CPE follows next on the scale due to relatively poorer performance in terms of elongation and then Neoprene due to reduction in tensile strength. PVC followed by Butyl showed the most adverse reaction to exposure to gamma radiation.

TABLE 8.2

EFFECT OF GAMMA RADIATION ON PHYSICAL PROPERTIES OF SELECTED POLYMERIC LINERS (REF. 25)

	PVC	High Density PE	Black XLPE	Unfilled XLPE	SBR	EPDM	EPM	Butyl	Silicone	Neoprene	Hypalon	Chlorinated PE
Original Properties												
200% Modulus, psi	2415	1000	1767	1260	580	1033	730	520	859	930	884	626
Tensile Strength, psi	2601	2213	2045	2272	1520	1443	872	798	1191	2544	2113	2170
Elongation at Break, %	250	640	270	480	460	470	300	450	290	550	560	670
200% Modulus, % Retention After Irradiation, Rads												
5×10^5	81	95	125	96	106	100	116	103	75	107	116	108
5×10^6	95	98	115	102	121	94	127	69	112	103	156	152
5×10^7	+	+	+	108	150	120	+	++	98	160	203	+
1×10^8	-	+	95	+	+	+	+	++	+++	-	-	-
Tensile Strength, % Retention After Irradiation, Rads												
5×10^5	80	96	122	102	98	104	101	96	76	104	106	112
5×10^6	88	98	112	97	100	97	106	56	100	98	113	98
5×10^7	61	123	101	70	82	93	119	++	100	77	124	135
1×10^8	-	118	95	59	40	79	90	++	+++	-	-	-
Elongation, % Retention After Irradiation, Rads												
5×10^5	100	103	104	90	93	111	96	93	107	96	89	99
5×10^6	80	103	96	96	96	102	81	87	90	93	86	63
5×10^7	40	-	48	58	70	47	41	++	34	46	59	18
1×10^8	-	2	37	25	33	32	26	++	+++	-	-	-

(a) Radiation Source - For exposures of 5×10^5, 5×10^6, and 5×10^7, cobalt-60 source was used (gamma = 1.17 to 1.332 meV and beta = 0.31 meV, at a dose rate of 5×10^5 rads/h). For exposure of 1×10^8, Esso Research and Engineering Company's radiation core in air and water was used, with the same dose rate as above.

+ Elongated less than 200%
++ Degraded (low strength due to chain scissions)
+++ Brittle
- No value reported

Additional information pertaining to the effects of radiation on polymeric lining materials reviewed for this study includes information from Kays (1978)(56) and from Schlegel Lining Technololgy(57).

Kays suggests that polymeric liners generally will absorb 10^{10} ergs of energy per gram of lining material before they are destroyed. Uranium ores release relatively low amounts of energy, in the 100 ergs per gram of lining material per hour range. Based on the above assumptions a time to destruction of 11,000 years is predicted(56).

Technical information provided by Schlegel(57) suggests that the mechanical properties of polyethylene change at a radiation dose of about 10^{10} rads. For a period of 1000 years this would correspond to 27000 rads per day and for radiation averaging 0.5 Mev a radioactive concentration of about 2 Ci/L would be required to produce a dose of 10^{10} rads(57). This activity is several orders of magnitude higher than would be expected in the uranium tailings considered in the study (see Section 6.4).

Based on the above discussion related to the effects of radiation on polymeric liners, it would appear that the polymers addressed in this study and in particular HDPE, Hypalon, CPE, EPDM and Neoprene are reasonably resistant to the medium term effects of radiation (10's of years). There is, however, insufficient information to provide even preliminary comments on the effects of long term (i.e. 100's of years) exposure to radiation.

8.3.3 Asphaltic Liners

8.3.3.1 General Chemical Resistance

There is significantly less published information available related to the general chemical resistance of asphaltic membranes than for polymeric membranes. In order to address general chemical resistance, reference is made to Section 5 of this report. Based on information summarized in Section 5 and the anticipated uranium mill tailings environment to which the asphaltic membrane would be exposed, the following comments are considered applicable:

i) Asphalt in general has excellent resistance to inorganic acids.

ii) Asphalt is resistant to mineral salts and alkalies up to concentrations of 30 per cent in solution.

iii) Asphalt can be attacked by microbes if not protected by biocides.

iv) Asphalt has poor resistance to hydrocarbons. It is soluble in solutions of 5 per cent hydrocarbons.

The above comments associated with the chemical resistance of asphalt would suggest that, in general, asphalt is resistant to the chemicals and agents anticipated in the tailings environment with the exception of concentrations of kerosene. However, as noted in Section 5, some of the rubbers used in asphalt/rubber compounds may be susceptible to acid attack(25). This would appear not to be the case for SBR/asphalt compounds(43).

8.3.3.2 Resistance to Uranium Tailings

The only known testing carried out to evaluate the effects of acidic uranium tailings leachate on asphaltic membranes has been conducted by Pacific Northwest Laboratories (PNL).(25, 41) The nature of the simulated tailings leachate which had a pH of 1.5 to 2.0 is described in Section 5.

An initial screening of catalytic airblown asphalt and asphalt/rubber membranes was carried out in exposure columns at elevated temperatures and partial oxygen pressures to simulate aging(25). The liners were evaluated in terms of permeability testing which indicated that the catalytic airblown asphalt had permeabilities ranging from 1×10^{-10} to 1×10^{-9} centimetres per second. Based on these test results an anticipated field liner permeability of 7×10^{-9} centimetres per second was predicted. Permeabilities of between 5×10^{-8} centimetres per second and 5×10^{-6} centimetres per second were measured for the asphalt/rubber membrane following 65 days of exposure. The relatively high permeability was considered to be associated with tears at the edge of the membrane caused by deflating the subsidence bladder in the column.

More detailed accelerated testing was also carried out on the catalytic airblown asphalt using the simulated acidic leachate noted above at pH 1.5 to 2.0(41). The accelerated testing was carried out through the use of increased temperatures and oxygen concentrations. Theoretical determinations indicated that for every increase of 10°C, the reaction rate increased by a factor of 2.3. The effect of temperature increase and the increased oxygen concentrations were considered to have produced an equivalent aging effect of 7 years over a 3 month period. It was also considered that increased acidity had little effect on aging. The results of the testing indicated that during the 3 month exposure, aging reactions of the asphalt membrane were limited to a penetration of the asphalt surface of only 10 to 40 m which amounted to 0.1 to 0.5 per cent of the total membrane thickness. By extrapolation, PNL suggested the asphaltic membrane had a lifetime in excess of 1000 years(41). More extensive testing would be required to confirm such extrapolation.

8.3.3.3 Resistance to Radiation

PNL estimated the effect of gamma radiation on asphalt liners by assuming a surface source for the tailings above the liner was given by the relationship:(25)

s = 1/2 SV where: s = surface source
SV = volume source
= relaxation length

The volume source used in the exposure calculation was considerably higher than would be expected from the uranium tailings. The anticipated absorbed energy from gamma radiation over a 1000 year period was 10^4 rad. A circular sample of each of the asphalt liners considered in the study was irradiated from a point source of cobalt-60 with 10^5 rad at the centre, and no physical defects were observed on the liner material(25).

8.4 Failure Mechanisms

The three major categories of liner or dam seepage barrier failure discussed in the following paragraphs are physical, chemical, and biological.

8.4.1 Physical Failure

Common types of physical failure include:

i) puncture
ii) tear
iii) abrasion
iv) cracking
v) overstressing
vi) creep

The first three types of physical failures listed above are generally associated with installation or operational damage to the liner by equipment, vandals, wildlife or plantlife. It is anticipated that careful base preparation, care during installation and the provision of an adequate soil cover as discussed in Section 7 would minimize the potential for these occurrences. Sterilization of the subgrade prior to liner system installation and chemical or physical barriers to burrowing animals and mammals would also reduce potential for these types of physical damage.

Cracking, not associated with adverse chemical reaction or resistance, would usually be related to climatic (notably ozone), ultra-violet and temperature effects. It is anticipated that the soil cover will reduce climatic effects but sections of the basin liners in slopes (and dams) not covered by substantial depths of soil or tailings would still be subjected to thermal stresses and freeze-thaw cycles possibly also aggravated by wet-dry cycles. It is considered that all of the liners, asphalt in particular, are susceptible to cracking due to climatic effects and cyclic environmental loadings even when provided with nominal soil cover.

Overstressing and creep failures would generally be related to containment facility operation. For example, under substantial depths of tailings, deformations of susceptible subgrades could occur in proportion to their compressibility and the applied surcharge. Liners must be sufficiently flexible to accommodate these deformations. In addition, where abrupt differential or shear deformations occur under loading due to abrupt changes in subgrade and/or basin geometry, rupture of the liner due to overstressing is a potential failure mechanism. This type of failure mechanism is particularly relevant for the northern Canadian environment considered in this study where significant changes in bedrock surfaces occur over very short distances and where depressions often contain peat or other highly compressible organic material. Under those circumstances it would be necessary to subexcavate and replace the more compressible materials prior to liner installation since it is considered that even flexible membranes cannot, in general, withstand the large potential strains. The ability of the liner to tolerate these movements will be a function of the liner thickness and flexibility at the discontinuity relative to the magnitude of deformation. Due to frictional resistance between the tailings/soil cover/liner/subgrade system it is doubtful whether significant areas of the liner beyond the zones of deformation would contribute to liner resistance to failure through elongation.

Liner materials placed on slopes and within dams would be subjected to shear stresses as tailings consolidate. Similar concerns are applicable where soil cover is provided over a liner on an overly steep slope. Slopes must be designed to provide a balance between shear stresses applied at the tailings/cover/liner interface and shear resistance available at the liner/underpad/subgrade interface to minimize shear failure. In a similar vein, while applied shear stresses on slopes may not reach levels required for shear failure, applied stresses should be suitably below peak strength so that creep of the soil-liner system is precluded. It is considered that soil-liner systems on slopes are susceptible to long term creep failure under relatively high applied shear stresses. As an additional precaution liners should always be provided with a suitable underdrainage system in slopes and in dams to preclude the detrimental effects of reduced effective stress and thus shear resistance due to excess pore pressure development in the zone immediately beneath the liner.

Other sections of this report have assumed that tailings basin side slopes and dam membranes will be constructed at 3 horizontal to 1 vertical and that the granular liner underpad used for illustration purposes and cost estimates will provide sufficient liner stability. Refinement of these details during the design phase will require laboratory and field testing.

Liner overstressing may also occur as a result of the generation of excess hydrostatic pressure and/or gas buildup. Excess hydrostatic pressure would occur where local water levels are generally above the liner bottom and, during operation, above the water levels within the impounded tailings. Hydrostatic pressures would be typically dealt with, either by installing a relatively extensive underdrainage and pressure relief system or by carefully staging and scheduling impoundment operation. This condition would be a common occurrence in northern Canada where local groundwater systems in valleys either correspond to the existing lake system or are above lake level and would thus be above valley alluvial materials upon which the liner would be founded. In this case, the alluvial materials would have to be satisfactorily dewatered to facilitate liner installation. Following installation and in order to avoid pressure relief systems prior to maintaining a tailings liquid level equal to or higher than the local groundwater level, the lined tailings impoundment area could be flooded.

Gas generation is usually associated with the degradation of organic materials such as peat left beneath the liner. In this case an extensive underliner gas collection and venting system similar to the pressure relief system discussed above would be required. The alternative would be to remove all organic materials and to then sterilize the subgrade. In fact, as discussed previously, it is doubtful whether a thin flexible membrane could be expected to perform satisfactorily when placed over peat or other compressive deposits.

8.4.2 Chemical Failure

Chemical failure of a liner system is very closely related to liner compatibility to a waste material and would represent an extreme case of incompatibility.

The common types of chemical failure for the liners being considered are:

i) swelling and extraction of plasticizers from polymeric liners in the presence of waste;

ii) degradation of all liner types due to exposure to ultra-violet light, oxygen, ozone and heat.

The mode of chemical failure would likely be rupture due to embrittlement, shrinkage, loss of strength, loss of puncture resistance, elongation, and/or creep and flow.

The tendency for different liner systems to degrade due to exposure to the elements has been reasonably well documented in publications and trade literature as discussed in Sections 4 and 5. The susceptibility of the liner types to the remaining classes of chemical failure will depend to a large extent on the results of compatability testing.

A general discussion related to the compatibility of the various liners with the anticipated nature of uranium mill tailings was presented in Section 8.3.

8.4.3 Biological Failure

The major concern associated with biological failure would be the susceptibility of a liner system to microbial attack where the liner is damaged and its structural integrity and seepage characteristics are affected. The plasticizers used in some polymeric liners such as PVC are particularly susceptible to biological attack.

The biological properties of the basin subgrade as well as the waste to be contained will require investigation if artificial liners are to be considered further. The relative resistance of the liner systems under consideration to biological attack may be initially considered based on the broad and very general associated information presented in the lining industry literature and discussed in sections 4 and 5.

Biological failure can generally be considered as a type of chemical failure due to their similarities in effect on the mechanical properties of the liners.

8.5 Mechanisms and Rates of Liner Degradation

Liner degradation, liner compatibility, chemical failure and biological failure are closely related and are difficult to separate. Liner degradation, as well as compatibility of the liner with the contained wastes, is generally addressed in terms of effect on physical properties with time.

Liner degradation is attributable to a number of mechanisms with the specific mechanism dependent on the type of liner membrane and the environment in which it is placed. Some of the known degradation mechanisms with brief explanations follow:

- o Extraction of plasticizers. Some membranes contain considerable amounts of various plasticizers imparting flexibility to the material. If the plasticizer migrates out of the membrane, hardening of the membrane may occur. Some PVC compounds are notoriously susceptible to this mechanism.

- o UV degradation. An exposed membrane, if not properly stabilized may be subject to the damaging effect of the UV component of solar radiation. Surface cracking is a result of UV degradation. All of the membranes would be susceptible to a degree but asphalt, PVC and low density polyethylene would likely be the most susceptible. Soil cover would probably alleviate this concern.

- o Biological attack. Some components of liner materials, for example plasticizers, may act as nutrients for various microorganisms. If the liner does not contain proper amounts of anti-microbial additive, it may be subject to attack by microorganisms. Change of colour, embrittlement and cracking may result.

- Ozone attack. Some elastomers, when stressed, may be subject to attack by environmental ozone. Surface cracking results. Special additives are incorporated in the elastomers to improve ozone resistance.

- Radiation. Polymeric materials are affected by both charged particles and ionizing radiation. Irradiation causes increase of crosslink density of materials resulting in hardening, decrease of the ultimate elongation and, sometimes, increase of tensile strength.

- Stress cracking. Polyethylene when subjected to stress and certain chemical agents including detergents will develop cracks. Some of the stress cracking agents will cause stress cracking when present at very low concentrations.

- Static and dynamic fatigue. Liner materials when subjected to constant or cycling stresses due to soil movement or temperature changes may eventually fail. The failure may be by the formation of major splits or by creation of micropores and increased seepage.

Attempts at predicting rates of degradation of thin membrane liners have been approached from three directions:

i) theoretical analyses
ii) laboratory evaluation
iii) field testing

The rates of degradation of a liner material are believed to depend on type of material, environment, stress and mechanism of degradation. Temperature is considered to be significant in assessing degradation rates for polymeric and asphalt membranes. The effects of temperature are generally assessed utilizing the Arrhenius equation:

$$dR/dt = A \exp(-E/KT)$$

where: - dR/dt is the change in property (eg. failure stress) with respect to time
- A is a constant
- K is the gas constant
- T is absolute temperature
- E is activation energy

Similar, generalized and widely accepted relationships are presently not available for other factors affecting degradation.

Pacific Northwest Laboratories are presently undertaking laboratory studies which include accelerated aging of asphaltic and some polymeric liners in the presence of simulated uranium tailings(25, 41). Aging is simulated by increasing temperature and partial oxygen pressure or oxygen content at the surface of the liner. The results of the accelerated testing are used to predict rates of degradation and, by extrapolation, liner life. The results of these tests have been discussed elsewhere in this report.

Matrecon(36, 29, 7) has carried out extensive testing of liners mostly in the presence of landfill or hazardous waste leachates and often at elevated temperatures in attempts to predict long term performance. The results of these tests are widely published.

There would appear to be relatively little published data associated with large scale field test programmes to evaluate rates of liner degradation under actual field conditions. Some information has however been obtained, most noteably the work carried out by the USBR at the Mt. Elbert Forebay reservoir (59). A 6 by 30 metre test section of reinforced CPE was installed at this site in order to investigate rates and mechanisms of degradation. Coupon sampling of the test section has been carried out for three years and is scheduled to continue for an additional 8 years. Degradation is being assessed in terms of effects on physical properties. The results of the testing carried out after 3 years burial are presented in Table 8.3. The most significant observations made following 3 years exposure are: (59)

i) A 9 to 15 per cent drop in Mullen burst resistance, a measure of puncture resistance.

ii) Ply adhesion showing strength of CPE/Fabric/CPE bond dropped by an average 24.6 per cent.

iii) The bonded seam shear strength and peel strength for the thermally bonded factory seams was 22.3 to 54.5 per cent lower than the original testing.

iv) The adhesive seam peel tests showed a 10.7 per cent drop and adhesive seam shear strength dropped by an average of 29.9 per cent.

TABLE 8.3

MT. ELBERT FOREBAY RESERVOIR TEST SECTION RESULTS
TEST SECTION PANEL NO. 3
36-MONTHS'S OF EXPOSURE (REF. 59)

Property	Blanket 570 panels 12-13 (thermal-hot air seam)			Blanket 2097 panels 27-28 (thermal-dielectric seam)		
	Original data	Aged data (range)	Percent change	Original data	Aged data (range)	Percent change
Weight gain	-	-	+15.6	-	-	+15.6
Mullen burst (kPa)	2997	2702 (2549-2756)	- 9.4	2811	2390 (2239-2480)	-14.9
Tear[a] (N)	355	300 (275-318)	-15.4	283	298 (282-318)	+ 5.3
Ply adhesion (N/m)	1505	1208 (1138-1225)	-19.7	1838	1295 (1225-1365)	-29.5
Bonded seam[b] shear (N)	1342	609 (587-627)	-54.6	1225	557 (485-592)	-54.5
Bonded seam peel (N/m)	5688	4130 (3990-4270)	-27.4	7368	5723 (5460-5950)	-22.3
Low temperature[c]	P	P	-	P	F	-
Adhesive seam[b] shear (N)	1339	948 (890-1099)	-29.2	1339	948 (890-1099)	-29.2
Adhesive seam peel (N/m)	6038	5390 (5163-5915)	-10.7	6038	5390 (5163-5915)	-10.7

Notes:

[a] Tear specimens. - Scrim sometimes pulled out due to delamination causing "roping" of scrim during test and, therefore, erratic test results.

[b] Shear seams. - Scrim pulls out of overlap relatively easily on the aged seams, whereas original seams failed in the parent material.

[c] Low temperature bend test at -40 °C (-40 °F) - P/F = pass/fail.

1 kPa = .145 lbf/in^2
1 N = .225 lbf
1 N/m = .0057 lbf/in

For the Mt. Elbert Forebay liner the major cause of drop in shear strength was water absorption of the CPE and as a result the scrim-CPE bond within the CPE had deteriorated and was reflected in loss of mechanical properties. Gas chromatography and mass spectrometry testing of the CPE following 36 months of exposure also indicated that some subtle changes in the CPE had occurred. These subtle changes were likely related to degradation of the polymer and/or effects of water absorption.

Considering the above discussion it is seen that research both in the laboratory and in the field is being carried out which addresses rate of liner degradation. There is, however, at this time insufficient information available to allow estimates of actual rates of liner degradation in most wastes, including uranium tailings leachate. However, most of the flexible liners considered show reasonable resistance to degradation in anticipated uranium tailings environment at least during periods of time measured in 10's of years. Little can be concluded in terms of periods measured in 100's of years. The exceptions and concerns would include:

i) The apparent negative effects of acids on Butyl and polyurethane.

ii) The PNL test results which show simulated leachate affected PVC and asphalt/rubber compounds.

iii) The poorer performance of PVC and Butyl when subjected to high levels of gamma radiation.

iv) The apparently significant effects of water absorption by CPE on some physical properties and in particular the scrim-CPE bond at the Mt. Elbert test section.

9. RESULTS OF INDUSTRY SURVEY

During earlier evaluation studies carried out for the liner industry a detailed list of producers, manufacturers, fabricators and installation contractors was prepared(66). The list is included with this report as Appendix C. It should be noted that this list was compiled in 1981 and is not entirely current. Specific changes of which we are aware are as follows:

i) Gundle Plastics, Inc., Dallas changed to
Gundle Lining Systems Inc.
Gundle Road
1340 East Richey Road
Houston, Texas
77073

ii) Gundle Lining Systems Ltd.
301-255 1st Street West
North Vancouver, British Columbia
V7M 3G8

iii) Synflex Industries, Inc., Vancouver
are no longer in business.

On the basis of Appendix C, a number of companies were contacted by telephone and in writing and were requested to forward an information package on liner products. The request was directed to a total of 15 companies as identified in Appendix D-1. To date 5 of these companies have responded and a summary of the information provided is included in Appendix D-2.

Based on discussions with the suppliers, representatives of the National Uranium Tailings Program, and colleagues, a list of liner users was compiled (Table 9.1). A questionnaire was forwarded to these users (Appendix E-1). The completed questionnaires are presented in Appendix E-2, and the results are summarized on Figure 6.

The liner users were grouped in three categories as noted below. Also noted is the response to date.

CATEGORY	NO. OF INSTALLATIONS	NO. OF REPLIES
North American Uranium Mining Industry	17	7
Canadian Mining Industry (excluding uranium)	8	5
Other Installations	9	5
TOTAL	34	17

The results of this survey, based on completed questionnaires, may be briefly summarized as follows:

1. Liner materials employed are HYPALON, PVC, HDPE, EPDM, CPE, and Asphalt, with HYPALON being the most common.

2. The largest single installation is Mt. Elbert Forebay, Twin Lakes, Colorado where more than 1 million square metres of CPE was installed.

3. All installations are reported to be operating successfully. It should also be noted, however, that most of the liners have only been installed within the last 5 years.

4. While many of the installations have monitoring systems in place, sufficiently detailed information to derive liner defects and release rates either does not exist or has not been provided with responses.

5. The most frequently mentioned problems relate to installation difficulties due to wind, rain, and cold temperatures.

6. There is no reported indication of chemical incompatibility between the liner and the waste.

We do not regard our survey of users as being statistically representative to a significant confidence level. The number of installations surveyed is small and to date only half of them have replied. Furthermore, the majority of the installations surveyed have been identified by the liner suppliers; it is reasonable that they would direct us to successes rather than failures. Finally, as has been earlier noted, most of the case histories are less than 5 years old; that is not a sufficient life span to start projecting 1000 year performance.

841-3015

TABLE 9.1 LINER USER SURVEY

CATEGORY I

URANIUM MINING INDUSTRY - NORTH AMERICA

	INSTALLATION	LINER TYPE	SIZE	LOCATION	OWNER	YEAR	CONTACT
i)	Evaporation Ponds for process leachate	PVC/CPE	$5.5\text{x}10^6$ ft^2	Bluewater (Grants) New Mexico	Anaconda Minerals Company		Mr. M. Stirland Grants
ii)	"	HYPALON	$3.8\text{x}10^6$ ft^2	Bluewater (Grants) New Mexico	Anaconda Minerals Company		Mr. M. Stirland Grants
iii)	Tailings Cells	PVC	$2.2\text{x}10^6$ ft^2	White Mesa Uranium Mill Blanding, Utah	Energy Fuels Nuclear Inc.		Mr. D.K. Sparling Blanding
iv)*	Uranium Tailings Pond	HYPALON	$6.5\text{x}10^6$ ft^2	Canon City, Colorado	Cotter Corporation	1978	Mr. Tim Smith Lakewood
v)	Leaching Pad			Denver, Colorado	Mobil Alternate Energy Inc.		Mr. W.A. Steingraber, Denver
vi)	Unknown	PVC/CPE	$6\text{x}10^6$ ft^2	Grants, New Mexico	Kerr McGee		Mr. W.J. Shelley Oklahoma City
vii)	Unknown	HYPALON	$1.5\text{x}10^6$ ft^2	Grants, New Mexico	Kerr McGee		Mr. W.J. Shelley
viii)*	Uranium Tailings	HYPALON	$2.5\text{x}10^6$ ft^2	Sweetwater Co., Wyoming	Minerals Exploration	1980	Mr. Tom Cline Rawlings
ix)	Uranium Tailings	HDPE	$2.8\text{x}10^4$ ft^2	Uravan, Colorado	Union Carbide	1980	Mr. R.G. Beverly Grand Junction
x)	Water Reservoir and Monitoring Ponds	HDPE	$7.9\text{x}10^5$ ft^2	Key Lake, Saskatchewan	Key Lake Mining Co.	1983	Dr. Bernie Rosner Engineering Director
xi)*	Tailings Dam Membranes	Oil Resistant PVC	$2.8\text{x}10^4$ ft^2	Dam No. 1 Williams Lake Tailings Management Area, Elliot Lake Ontario	Denison Mines Limited	1979	Golder Associates

NOTE: * - Questionnaire Returned.

TABLE 9.1 (Continued)

CATEGORY I (Continued)

	INSTALLATION	LINER TYPE	SIZE	LOCATION	OWNER	YEAR	CONTACT
xii)*	Uranium Tailings Pond	HDPE/EPDM Alloy	$1.22\text{x}10^6$ ft^2	Ford, Washington	Dawn Mining Co.	1981	Mr. Bob Nelson, Ford, Washington
xiii)*	Tailings Dam Membranes	HYPALON	$5.7\text{x}10^5$ ft^2	Panel Tailings Area, Elliot Lake, Ontario	Rio Algom	1978-79	Golder Associates
xiv)*	Tailings Ponds	HYPALON	$3.9\text{x}10^6$ ft^2	Spokane, Indian Reservation, Washington	Western Nuclear Inc.	1977-79	Mr. Ken Miyoshi Wellpinit, Wash.
xv)*	Tailings Dam Membrane	HYPALON	$1\text{x}10^5$ ft^2	Dam 10 Elliot Lake, Ontario	Denison Mines	1971-72	Golder Associates
xvi)	Leachate Collection pad beneath ore stockpile	PVC	$1.2\text{x}10^6$ ft^2	Agnew Lake Mines, Espanola, Ontario	Kerr Addison	1975-78	
xvii)	Various Installation	-	-	New Mexico	New Mexico EID Radiation Protection Bureau		Miss Maxine Goad Sante Fe

NOTE: * - Questionnaire Returned.

TABLE 9.1 (Continued)

CATEGORY II

MINING INDUSTRY CANADA

	INSTALLATION	LINER TYPE	SIZE	LOCATION	OWNER	YEAR	CONTACT
i)	Unknown	HYPALON	6x10^{4} ft^{2}	Vancouver, B.C.	Rio Algom	1979	
ii)	Gypsum Sludge Pond	HDPE	1.23x10^{6} ft^{2}	Fort Saskatchewan, Alberta	Sherritt Gordon Mines Ltd.	1982	Mr. Ingo Sintenis (403) 998-6394
iii)	Tailings Dam Membrane	PVC	2150m long	Detour Lake, Ontario	Detour Lake Joint Venture	1982	
iv)*	Tailings Dam Membrane	CPE	3.75x10^{4} ft^{2}	Copper Cliff, Ontario	Inco	1977	Mr. E. Armitt Copper Cliff
v)*	Brine Storage	HDPE	8.6x10^{5} ft^{2}	Rocanville, Saskatchewan	Potash Corp. of Saskatchewan	1982 1983	Mr. Morris Ennis Saskatoon
vi)*	Tailings Dam Membrane	PVC	7x10^{4} ft^{2}	Falconbridge, Ontario	Falconbridge Mines	1978	Mr. R.S. McLatchie Falconbridge
vii)*	Brine Dykes	HYPALON CPE	Small	Colonsay, Saskatchewan	Central Canada Potash	1981 1982	J.D. Wild Colonsay
viii)*	Brine Storage	HYPALON	5.5x10^{4} ft^{2}	Saskatoon, Saskatchewan	Potash Corp. of Saskatchewan	1976	M.O. Davyduke

NOTE: * - Questionnaire Returned

CATEGORY III

HAZARDOUS WASTE STORAGE

	INSTALLATION	LINER TYPE	SIZE	LOCATION	OWNER	YEAR	CONTACT
i)	Landfill	HDPE	2.6×10^5 ft^2	Williamsburg, Ohio	Clermont Environmental Reclamation Co.	1982	
ii)	Landfill	HDPE		Model City, New York	SCA Chemical Services		Mr. Paul Letki Model City
iii)*	Evaporation Ponds Flyash Ponds	HDPE	2.9×10^6 ft^2	Pawnee Power Station Brush, Colorado	Public Service Corp. of Colorado	1979 1980	Mr. Roy Henderson
iv)	Various Waste Installation	ASPHALT		Morrisville, Penn.	Waste Management Inc.		Mr. Gary Brown
v)*	Brine Pond	HDPE	1.3×10^4 ft^2	Fort Saskatchewan Alberta	Chevron, Canada	1982	R.C. Edlund Calgary
vi)	Brine Pond			Redwater, Alberta	Procor Limited		
vii)*	Brine Ponds and Chemical Storage Lagoons	ASPHALT, EPDM	6.6×10^5 ft^2	Amherstburg, Ontario	Allied Chemical Limited	1966 to 1981	Golder Associates
viii)	Water Reservoir Forebay	CPE	12.6×10^6 ft^2	Mt. Elbert Forebay Twin Lakes, Colorado	U.S.B.R.	1980	Published Papers
ix)*	Brine Pond	PVC HYPALON	3.2×10^5 ft^2	Fort Saskatchewan	Dome Petroleum	1981	Dennis W. Huber

10. RELEASE MECHANISMS AND RATES

10.1 Release Mechanisms

The mechanisms by which contaminant flow and seepage occurs through thin flexible polymeric and asphaltic membranes are:

i) Fluid passage through the intact membrane by diffusion under vapour pressure differential, osmosis due to chemical gradients, and absorption due to polymer and asphalt solubility.(14, 60)

ii) Fluid flow through defects including pinholes, punctures, tears, poor seams, or otherwise damaged portions of the liner.

Mechanism ii) above is the most significant in terms of liner field performance and seepage quantity. It is also very difficult to quantify.

Similarly, predicting flow through intact liner materials (release mechanism i) is also difficult to quantify. The resistance of a geomembrane to fluid flow is typically discussed in terms of hydraulic conductivity or pemeability. The mechanism by which fluids pass through membranes is different from the mechanism by which fluids pass through soils and Darcy's law does not generally apply. Further, the hydraulic conductivity of small laboratory specimens cannot be measured(60). Values for liner permeability quoted in the literature are generally based on perm rating or the amount of water vapour that passes through the lining under a vapour pressure differential at constant temperature. Permeability based on a conversion from perm rating is not strictly correct(14).

It is convenient to evaluate permeability of geomembranes using coefficients originally defined for soils. Further, apparent field or global hydraulic conductivity which includes the effects of defects is considered to be a reasonably valid concept. For a given hydraulic head, a given liner thickness and area, and a known seepage quantity over a period of time, the flow through the liner can be described in terms of coefficient of permeability or hydraulic conductivity with units of length per unit time. To remain consistent, for discussion purposes, the term permeability will be used to describe the rate at which seepage occurs through the liner.

The equivalent permeability of an intact polymeric or asphaltic liner, accurately determined, would be extremely low; probably lower than 10^{-12} centimetres per second for most polymerics and lower than 10^{-10} centimetres per second for asphaltic liners. Where permeabilities for polymerics as high as 10^{-9} centimetres per second and for asphalt as high as 10^{-7} centimetres per second are quoted in the literature it is likely that these values either represent flaws in sample, leakage in the test apparatus or an attempt by the author to predict field or apparent liner permeability.

10.2 Release Rates

Estimates of release rates or the quantity of seepage which flows through a liner may be made using generally accepted flow equations. Information required includes knowledge of the global or apparent permeability of the installed liner and the hydrogeology of the impoundment site.

As noted the permeability of the liner is largely dependent on the type and density of liner defects and consequently, is specific to liner, installer and site. If a perfect liner system without defects were possible then seepage quantities based on hydraulic conductivities in the order of 10^{-12} and 10^{-10} centimetres per second or lower for polymeric and asphaltic liners, respectively, could be expected. It is not reasonable, however, to assume that over large areas of liner installation (tens of hectares) a perfect liner could be constructed. Nevertheless, occurrence of defects can be greatly reduced by carefully following construction procedures outlined in Section 7, since most serious defects occur during installation and go undetected. It is also known that some liners by their nature would tend to have more flaws than others. Sprayed-on asphalt liners for example are susceptible to variable rates of application and discontinuities and for single applications relatively higher field permeabilities would be anticipated. Polymeric liners because they are manufactured are of generally uniform thickness but are susceptible to field seam flaws due to the great lengths of seams required. Inspections and testing during installation is, however, more readily carried out for polymeric liners and for this reason it should be possible to construct a relatively intact polymeric liner.

A rational approach to evaluating apparent or field liner permeabilities is through detailed monitoring of existing installations and back calculating apparent permeabilities based on measured seepage volumes, known hydraulic heads, liner thicknesses and liner areas. In this way the effects of both the waste on the liner and liner defects can be evaluated. Relatively small scale laboratory testing would typically only evaluate the effect of the leachate on liner permeability usually due to swelling. For the purpose of this study an attempt was made to collect this type of information in order to evaluate field permeabilities. However, as noted in Section 9 and Appendix E insufficient information was collected. This is a promising approach and is worth pursuing in more detail.

In order to estimate seepage losses from uranium tailings impoundment sites for the purpose of this study it will be necessary to rely on published information for liner permeability and to attempt a rational increase in the value to account for unavoidable flaws. Consideration is also given to field hydraulic conductivities reported by others(14, 60). For a polymeric liner with a defect free equivalent permeability of 1×10^{-12} centimetres per second, it is considered reasonable to assume that installed permeability should not be significantly higher than 1×10^{-10} centimetres per second assuming that the liner has been properly selected, designed, installed and inspected. A similar estimation for installed permeability of asphalt is more difficult. An installed permeability of 1×10^{-8} centimetres per second has been selected for asphalt for purposes of analysis and to demonstrate the relative effects of liner permeability on release rates.

Site hydrogeology is significant in that it will dictate the nature and rate of seepage flow and contaminant transport from the underside of liner to the groundwater system. Flow models which consider the nature of flow beneath tailings impoundments and take into account criteria such as unsaturated flow, movement of the wetting front, position of the phreatic surface, and saturated flow following groundwater mounding have been presented by others(61).

10.3 Elliot Lake

For the typical Elliot Lake sites described in Sections 6 and 11 and shown on Figures 7 to 10, it is anticipated that significant hydrogeological and topographical conditions may be summarized as follows:

i) Groundwater levels in topographical lows would typically correspond to pond or lake levels.

ii) Groundwater levels in adjacent valley walls would typically correspond to or be above lake level.

iii) The soil immediately underlying the liners would typically have permeabilities at least 4 orders of magnitude (10,000 times) higher than the liner thus allowing the assumption that steady state flow conditions prevail.

iv) Maximum height of tailings (and pore fluid) is 22 metres; average height is 11 metres.

v) Area of tailings basin 232 hectares (2.32×10^6 m^2)

vi) Representative permeability of tailings 1×10^{-5} centimetres per second.

vii) Tailings would be located in a recharge area with water levels typically 11 metres above the base of the basin liner (see Section 6) and 11 metres below the tailings surface.

Based on the results of the analyses presented on Figure 12 the following comments may be made:

i) Seepage from an unlined basin is computed to be 232 litres per second. More rigorous analyses for actual tailings basins have indicated substantially lower seepage volumes due to more favourable hydrogeological conditions than those assumed for the model. This numer is felt to be significant, not in absolute terms, but in evaluating the effect of liners on seepage reduction.

ii) Based on conditions shown on Figure 12 an asphalt membrane 8 millimetres (315 mils) thick would reduce seepage from the impoundment by about 40 per cent from the condition where no liner is present beneath the tailings.

iii) A polymeric membrane 1.5 millimetres (60 mils) thick would reduce seepage from the impoundment by more than 90 per cent from the condition where no liner is present.

10.4 Southeastern Athabasca

The typical southeastern Athabasca site is described in Sections 6 and 11. The anticipated significant hydrogeological and topographical conditions may be summarized as follows:

(i) Groundwater levels near ground surface.

(ii) Steady state flow conditions.

(iii) Average thickness of tailings (and pore fluid) is 4.5 metres.

(iv) Area of tailings basin 36 hectares (0.36×10^6 square metres).

(v) Representative permeability of tailings 1×10^{-5} centimetres per second.

(vi) Tailings would be in a recharge area with water levels typically below the base of the tailings basin.

Based on the results of the analyses presented on Figure 13, the following comments may be made:

i) Seepage from an unlined basin is computed to be 36 litres per second.

ii) Based on conditions shown on Figure 13 an asphalt membrane 8 millimetres (315 mils) thick would reduce seepage from the impoundment by about 60 per cent from the condition where no liner is present beneath the tailings.

iii) A polymeric membrane 1.3 millimetres (60 mils) thick would reduce seepage from the impoundment by more than 95 per cent from the condition where no liner is present.

11. LINER COSTS

11.1 Elliot Lake

11.1.1 General

Consistent with the terms of reference, liner and related costs have been estimated for the containment of 20 years of uranium wastes. The costs are based on producing 2.27 million kilograms (5 million pounds) of U_3O_8. Assuming a low grade mineralogy (0.1 per cent of U_3O_8), similar to Elliot Lake, the 20 year operation would produce 37 million cubic metres of tailings.

The Quirke tailings basin of Elliot Lake has been chosen as typical for this study and is outlined on Figure 7. Total area of this basin is 2.32 million square metres. Costing is based on draining the lake, constructing dams as indicated on Figure 7, and filling the basin to a maximum depth of about 22 metres and an average depth of about 11 metres over the 20 year project life.

Only the major components of cost have been included in this analysis. While the unit prices used are based on ongoing experience in Elliot Lake, they may be neither accurate or current. Accordingly, the total tailings management costs are approximate and should be used for conceptual evaluation only.

11.1.2 Drainage

The lake will require drainage. Approximately half the total area occupied by the tailings basin shown on Figure 7 is assumed to be occupied by lake and average lake depth is estimated to be 2.5 metres. Based on dewatering at the rate of 380 litres per second (5000 g.p.m.), a 3 month dewatering period is anticipated at a cost of $270,000.

11.1.3 Site Preparation

Site preparation will include clearing, grubbing, subexcavation, rock excavation and site grading as described below.

As noted, half the area is assumed to be pond so the other half will require clearing and grubbing. At $4,000 per hectare the cost is $460,000.

Subexcavation is based on removing and disposing of 1 metre of lake sediments and organic soil over the entire pond area. Elsewhere it is assumed that only 150 millimetres of subexcavation is required.

Total perimeter of the tailings area is 8.3 kilometres and rock excavation is anticipated (to obtain 3:1 slopes) over about 10 per cent of the length. Furthermore, in the areas of rock excavation, 300 cubic metres per lineal metre is anticipated (Figures 8 and 9). Accordingly the total quantity of rock excavation is 249,000 cubic metres.

The final item of site preparation is site grading to prepare a reasonably smooth and planar surface on which to install a membrane. This will consist of removing asperities and for the purpose of this computation we have assumed 150 millimetres (cut or fill) over the entire area outside of the pond.

11.1.4 Dams

The locations where dams are required is shown on Figure 7 and a total length of 3320 metres is indicated. A typical dam section (for costing purposes) is shown on Figure 10. Based on this section we have estimated the material requirements as 40 per cent select granular and 60 per cent inexpensive core material.

11.1.5 Liners

Polymeric Membranes

Only limited response to the survey of suppliers was obtained. The information pertaining to costs is summarized on Figure 11. Also shown is information collected by Golder Associates in 1981(66) together with information published by Schmidt in 1983(63). Suggested ranges for installed current costs of four of the more widely used polymeric membranes are indicated. As might be expected, prices for the four classes of material shown vary linearly with thickness of material.

Asphaltic Liners

Current costs were not obtained. Figures reported by Golder Associates in 1981 (66) and Pacific Northwest Laboratories in 1983 (41) are noted below.

TYPE	APPLICATION RATE (litres/m^2)	INSTALLED COST ($/m^2)	INFORMATION SOURCE
Catalytic airblown asphalt	5.5 to 8	4.80 - 6.90	Golder 1981 (66)
Catalytic airblown asphalt	9	3.30	PNL 1983 (41)
Asphalt - rubber	5.4	3.10	PNL 1983 (41)

11.1.6 Soil Cover

Soil cover is necessary for some liners and desirable for all. Similarly, prepared soil bedding is desirable. The costs are based on providing 300 millimetres of sand above and below the liner (a total of 600 millimetres).

11.2 Southeastern Athabasca

11.2.1 General

Various documents, including the Kilborn/Melis report (67), indicate a Key Lake tailings basin in an area of low relief and measuring about 650 metres square. This study assumes that such a basin would be built using ring dykes constructed from material excavated from the pond interior.

The high grade ore in Southeastern Athabasca (2.5 per cent U_3O_8) would yield only 4 per cent of the tailings generated by Elliot Lake. Over a 20 year life 1.5 million cubic metres of tailings would be generated. For the above noted area, dykes of 6.5 metres would be sufficient to contain the tailings and provide 2 metres free board. Optimization studies would be required to determine the most economical area of basin and height of dykes.

The Kilborn/Melis report (67) notes Saskatchewan and Elliot Lake 1984 labour rates to be $50 per hour and $35 per hour, respectively. These relative rates have been used to derive unit costs for Saskatchewan. The unit costs in Table 11.1 (Elliot Lake) have been increased by the ration 50:35 to determine the unit costs in Table 11.2 (Southeastern Athabasca).

11.2.2 Site Preparation

Site preparation will include clearing, grubbing, subexcavation and site grading in a similar manner to that discussed for Elliot Lake. It is, however, assumed that there will be no requirement for pond drainage or rock excavation.

11.2.3 Dams

It is assumed that an area measuring 650 metres will be surrounded by ring dykes/dams. These dykes will be of similar proportions to the dam section shown on Figure 10 but they will be much smaller. The dykes will have 2:1 and 3:1 outside and inside slopes, respectively and will have a maximum height of 6.5 metres from crest to pond bottom.

11.2.4 Liners

Based on information from various suppliers, it is anticipated that the installed cost of polymeric liners in Southeastern Athabasca would be about $1.00 per square metre greater than those shown on Figure 11. This increase is incorporated into Table 11.2 together with a similar increase for asphalt.

11.2.5 Soil Cover

The cost estimate assumes 300 millimetres of soil bedding and cover, below and above the lining.

11.3 Summary

The liner costs are summarized in Tables 11.1 and 11.2. While costs are large ($15 million to $29 million for the Elliot Lake and $3 million to $6 million for Southeastern Athabasca) for the three candidate liners noted, they are overshadowed by the cost of the related liner works. For example, with 36 mil reinforced Hypalon, total facility cost is $81 million for Elliot Lake and $15 million for Southeastern Athabasca; less than 30 per cent of that cost is for supply and installation of the Hypalon. Similarly, based on the costs noted, asphalt represents just over 20 per cent of a total cost of $74 million for Elliot Lake and $14 million for Southeastern Athabasca. Similarly, HDPE represents less than 35 per cent of total costs of $89 million and $17 million for Elliot Lake and Southeastern Athabasca, respectively.

The terms of reference indicate a 20 year production of U_3O_8 of 45,000 tonnes. Referring to Table 11.1, the cost of tailings containment per tonne for the lining materials noted would range from $1600 to $2000 per tonne for Elliot Lake. Corresponding costs for the higher grade ore in Southeastern Athabasca are less than $400 per tonne.

Finally, it should not be inferred that the three membrane materials chosen for costing are totally equivalent to each other with respect to performance, durability, etc. The relative merits of these materials are discussed in other sections of this report.

TABLE 11.1

LINER COST SUMMARY

Elliot Lake

ITEM	QUANTITY	UNIT COST	AMOUNT ($\$x10^6$)
Pond Drainage	89 days	\$3,000.00	0.27
Clearing and Grubbing	116 ha	\$4,000.00	0.46
Subexcavation	$1334x10^3$ m^3	\$ 10.00	13.34
Rock Excavation	$249x10^3$ m^3	\$ 33.00	8.22
Site Grading	$174x10^3$ m^3	\$ 4.50	0.78
Dam (Core)	$1240x10^3$ m^3	\$ 4.50	5.58
Dam (Select Granular)	$827x10^3$ m^3	\$ 16.00	13.23
Soil Cover and Bedding	$1462x10^3$ m^3	\$ 12.00	17.54
TOTAL CIVIL WORKS			\$59.42
36 mil reinforced Hypalon	$2436x10^3$ m^2	\$ 8.80	21.44
60 mil HDPE	$2436x10^3$ m^2	\$ 12.00	29.23
300 mil Catalytic air blown asphalt	$2436x10^3$ m^2	\$ 6.00	14.62

TABLE 11.2

LINER COST SUMMARY

Southeastern Athabasca

	QUANTITY	UNIT COST	AMOUNT ($\$ \times 10^6$)
Pond Drainage	Nil		0
Clearing and Grubbing	42 ha	\$5,700.00	0.24
Subexcavation	63×10^3 m^3	\$ 14.50	0.91
Rock Excavation	Nil	\$	0
Site Grading	63×10^3 m^3	\$ 6.50	0.41
Dam (Core)	215×10^3 m^3	\$ 6.50	1.40
Dam (Select Granular)	144×10^3 m^3	\$ 23.00	3.31
Soil Cover and Bedding	266×10^3 m^3	\$ 17.00	4.52
TOTAL CIVIL WORKS			\$10.79
36 mil reinforced Hypalon	444×10^3 m^2	\$ 9.80	4.35
60 mil HDPE	444×10^3 m^2	\$ 13.00	5.77
300 mil Catalytic air blown asphalt	444×10^3 m^2	\$ 7.00	3.11

12. WARRANTIES

12.1 Polymeric Liners

Most polymeric liner manufacturers and fabricators have standard warranty forms, examples of which are included in Appendix E. In the past the typical warranty period has been 20 years while current practice indicates shorter warranties. However, manufacturers indicate flexibility in negotiating special warranties for specific projects and applications.

The actual terms of the standard warranties and the extent of liability of the manufacturers and fabricators are generally uniform. Based on current submissions, as well as a survey conducted in 1981, the following main clauses are noted:

i) Material

The supplier warrants that the material supplied to be free of any defects in materials and/or workmanship at the time of sale. For this clause to be enforced it must be demonstrated to the supplier's satisfaction that the defect was present at the time of installation.

In some cases the supplier also warrants that the material sold will meet or exceed the published or agreed specifications for the material.

ii) Service Life

The supplier warrants that the liner as supplied will have a useful life from the date of sale for a period of 20 years (typical) under the normal uses and service for which it is designed in any customary weather which may be encountered and which is not customarily considered to be in the nature of an act of God, casualty or catastrophe such as (but not limited to) earthquake, flood, piercing hail, tornado, etc. Normal use and service excludes among other things the exposure of the liner to harmful chemicals, mechanical abuse by machinery, equipment or people, or excessive pressures or stresses from any source.

The supplier generally requires approval of the liner design, the intended use and the nature of the stored materials. Any substantial change in use or operation of the containment facility without prior agreement with the supplier would invalidate the terms of the warranty.

The warranty of one manufacturer requires that the liner be covered with earth at all times and also requires the maximum temperature and pH range of the stored material to be specified in advance.

iii) Installation

A separate installation/workmanship warranty is also often provided by the installing contractor. This normally covers field seams for a period of one to two years.

If the liner is installed without the supplier's technical supervision and/or control or if the installation is carried out by a non-approved contractor, the material warranty would not be enforceable.

iv) Repair or Replacement

Should defects or premature loss of use within the scope of the warranty occur, the supplier will either repair or replace defective materials, at his own discretion, on a pro-rata basis at the then current price in such a manner as to charge the purchaser for that portion of the warranged life which has elapsed since purchase of the material. In addition, any defect or claim for alleged breach of warranty must be made to the supplier within thirty days of the alleged defect being first noted. In some cases if the supplier can demonstrate that:

i) the defect occurred prior to thirty days of it being reported to him and that;

ii) the purchaser under normal operations should have detected the defect prior to that time;

this may invalidate this clause of the warranty.

Although not clearly specified in most standard warranties, locating of and access to the defective portions of liner, must be provided by the purchaser at no cost to the supplier.

v) Liability Limitations

The supplier's liability under the warranty shall in no event exceed the amount of the sale price of the material sold to the purchaser for the particular installation in which it failed.

The supplier, under no circumstances shall accept any liability for any special, direct, indirect or consequential damages arising from loss of production or any other losses owing to failure of the material or installation.

vi) Repairs by Others

No allowance will be made for repairs, replacements or alterations made by the purchaser unless with the supplier's consent in writing.

12.2 Asphalt

Typical warranties for thin, flexible asphalt liners were not obtained during this study. Warranties would likely be negotiable with the manufacturer/supplier/installer, as is the case for polymeric membranes. Furthermore, the warranty format used for polymeric membranes would represent a suitable starting point to develop a warranty for asphalt liners.

12.3 Summary

The social and financial implications of the failure of any waste facility are high and because of this undue attention is sometimes focused on warranties. Warranties will only cover some portion of the cost relating to supply and installation of the liner. They do not cover the consequential costs of failure or the costs of related civil works. These latter costs alone can exceed liner costs by 3 to 4 times (Section 11.7). Accordingly, while material and installation warranties are both desirable and appropriate, they do not preclude the need for sound design and reputable and experienced suppliers and installers.

13. TEST PROGRAM FOR THE LONG-TERM STABILITY OF FLEXIBLE LINES - PHASE II

13.1 Requirements of Test Program

This study (Phase I) comprises an in-depth evaluation of 9 polymeric lining materials and 3 asphaltic membranes. Each of the materials has inherent advantages and disadvantages and many of these have been identified, particularly with respect to physical and chemical compatibility with various substances. Nevertheless, detailed information is required with regard to:

i) Compatibility with the specific waste to be contained, and

ii) Long term degradation.

The materials being considered are all relatively new (less than 20 years) to the waste containment field. While it is both desirable and essential that case histories be further probed, this must be accompanied by accelerated testing in order to make projections for 1000 year performance. The accelerated program of testing is described in the following paragraphs. The case history analyses will be continued in a similar manner to that carried out in Phase I.

13.2 Approach

Long term properties of materials may be evaluated based on the Arrhenius equation:

$$dR/dt = A \exp(-E/KT) \qquad (1)$$

where dR/dt is the reduction in property with respect to time, A is a constant, K is the gas constant, T is absolute temperature, and E is the activation energy. Integration of the equation (1) results in:

$$\mathrm{Ln}\ t = (E/K)\ 1/T + B \qquad (2)$$

A plot of Ln t versus 1/T is then a straight line of slope E/K, and is known as an Arrhenius plot[(64)].

Tests may be conducted at elevated temperature and the results extrapolated to ambient temperature but first, failure criteria have to be established. For a liner, these may be based on degradation of mechanical properties and the resultant increase of permeability. The liner may be assumed to have failed, for example, if its tensile strength drops below 20 per cent of its original value and permeability increases 100 per cent or more.

To determine the time to failure of a membrane exposed to the tailings at 20°C. Samples of the membranes will be exposed to the tailings in the laboratory at elevated temperatures, say 80, 70, 60, 50°C for a period of 1-1/2 years and their tensile strength would be tested four times. The plot of tensile strength as a function of time is plotted on semi-log graph for these four temperatures as shown on Figure 14(a). The lines are extrapolated to establish time to failure. From that graph, time to failure is established for four temperatures.

As a second step, an Arrhenius plot of time to failure versus temperature is prepared as shown on Figure 14(b). By extrapolation of that curve one can estimate the time to failure of the membrane at 20°C. A similar exercise may be carried out with regard to other properties.

13.3 Methodology

The proposed program will consist of two parts. In Part 1, six of the twelve liner materials will be selected and some of their properties evaluated. Based on the results and the other considerations outlined in this report, three liners will be selected for testing in Part 2. The objective of Part 2 will be to estimate time to failure of the liners. The methodology used will be based on the Arrhenius equation discussed above. The time to failure will be established both for the liners as well as for the "field seams" prepared in the laboratory under controlled conditions.

Part 1 - Screening

The permeability, tensile strength, elongation and field seam strength for the six preselected liners will be determined. Short-term compatibility with both Elliot Lake and Southeastern Athabasca tailings will be established by immersion in tailings in the laboratory. Tailings could be obtained either field sampling from existing tailing ponds or chemically simulating the porewater of tailings and mixing in silica sand for the solids in the tailings. The former, sampling of actual tailings, is recommended. After two months exposure the samples will be retested. Based on the test results and previously noted considerations, three liners and one of the two tailings will be selected for further testing in Part 2.

Part 2 - Detailed Testing

The first task in Part 2 will be to define appropriate failure criteria in terms of the change in the permeability and the mechanical properties. When the failure criteria have been established, samples of the three selected liners will be prepared for the long-term stability testing program. Large heated tanks of the selected tailings will be set up at four different temperatures. Samples of the liners will be prepared on frames with 0, 5 and 10 per cent strain. Samples of the field seams for each material will also be prepared. A set of samples from each liner would then be conditioned in one of each of the three heated tailings tanks. At five separate time spans from two months to two years, the time increment to be exponential, samples from each material for the three different strain levels will be removed from the tanks and tested for permeability, tensile strength and elongation.

The resulting data would then be analysed and time-to-failure established.

13.4 Anticipated Degree of Success

The methodology described above results in predictions of moderate accuracy. The accuracy of the prediction decreases with the increase of the extrapolated time. It is usually not recommended to extrapolate more than a factor of 10 (i.e. 1 year to 10 years, 10 years to 100 years, etc.). The results are only meaningful if the aging mechanism is well reproduced. If the tests are run at too high a temperature, the aging mechanism may be changed producing misleading results. Accuracy of the extrapolation will also decrease with increase of the standard deviation of the results.

It is anticipated that the 2-1/2 year accelerated program will permit prediction of the selected properties of the liners after 20 years. The results may be further extrapolated to 200 years producing less accurate results. Any further extrapolation will probably produce results which are meaningless. The proposed program will deal with normal deterioration of the liner and the seam subjected to a tailings environment. Time to failure predictions will not take into account accidental events such as soil movement, attack by animals, installation damage, etc.

13.5 Program Costs

The approximate cost of the Phase II program, as outlined in the foregoing paragraphs, is noted in Table 13.1. These costs are based on a 2 month Part 1 program, a 24 month Part 2 program, and a 4 month collation and final report period.

The cost of the project is substantially influenced by the number of conditions used in Part 2. The cost given in Table 13.1 is based on testing of 3 membranes in 1 tailings at three strain conditions and 5 times. If only unstrained membranes are tested at 4 times the total cost would reduce by about $100,000.

Finally, consideration might be given to postponing the laboratory portion of Phase II until the industry survey is complete. An exhaustive industry survey could be completed for under $100,000.

TABLE 13.1

PHASE II TEST PROGRAM COST SUMMARY

1. PROJECT ENGINEERING		
- Project Manager	$ 20,000.00	
- Project Engineer (1/4 time)	$ 60,000.00	
- Support Staff	$ 30,000.00	
- Disbursements	$ 15,000.00	$125,000.00
2. SAMPLING AND DISPOSAL OF TAILINGS		15,000.00
3. LABORATORY - PART 1		
Set up and development of permeability test procedure	$ 15,600.00	
Initial testing permeability, tensile strength and elongation - 6 membrane @ $800.00 each	$ 4,800.00	
Testing after exposure to tailings for 2 months, 6 membranes, 2 tailings @ $800.00 each	$ 9,600.00	$ 30,000.00
4. LABORATORY - PART 2		
Set up	$ 15,000.00	
Testing - 3 membranes, 1 tailings, 4 temperatures, 3 strain conditions, 5 times. 180 tests @ $800.00 each	$144,000.00	
Data analysis	$ 20,000.00	$179,000.00
5. CASE HISTORY SURVEY		$ 30,000.00
6. QUARTERLY MEETINGS 10 @ $2,500.00		$ 25,000.00
7. REPORTS		
4 Interim @ $5,000.00	$ 20,000.00	
1 Final @ $15,000.00	$ 15,000.00	$ 35,000.00
TOTAL ESTIMATED COST		$439,000.00

14. CONCLUSIONS AND RECOMMENDATIONS

Flexible liners show considerable promise for the containment of waste materials including uranium tailings. Nine polymeric linings and three types of sprayed asphalt have been considered with respect to the physical and chemical environment in the uranium producing areas of Canada. All indicate good chemical resistance to uranium wastes but are subject to installation problems.

High density Polyethylene, Hypalon, and Chlorinated Polyethylene (HDPE, CSPE and CPE) all exhibit sufficiently good characteristics to warrant further study. Furthermore these materials have been used in major installations throughout North America. Such experience is not available for the asphaltic membranes but at least one should be selected for further study. Information to date would favour either catalytic airblown asphalt or one of the asphaltic-elastomeric compounds.

The intact membranes (asphaltic or polymeric) have an extremely low permeability, probably less than 1×10^{-11} centimetres per second. However, the operative permeability is substantially higher and values which are typically used are 1×10^{-8} and 1×10^{-10} centimetres per second for asphaltic and polymeric liners, respectively. These higher values of permeability reflect liner defects, installation problems, and liner degradation.

Conceptual design of a tailings basin has been carried out for both Elliot Lake and Southeastern Athabasca conditions assuming the following permeabilities:

o Asphaltic membrane	1×10^{-8} cm/sec
o Polymeric membrane	1×10^{-10} cm/sec
o Tailings	1×10^{-5} cm/sec
o Subgrade	1×10^{-4} cm/sec

Assuming the validity of Darcy's law then the asphalt is least effective while the polymeric membrane reduces seepage to less than 10 per cent of that of an unlined facility. An even larger reduction in seepage would be calculated if it could be demonstrated by laboratory and field testing, that the operative permeability for the thin flexible liners is lower than the above-noted values.

An industry survey carried out as part of this study (Phase I) has provided positive but inconclusive results. This study should continue in Phase II. Concurrently, or subsequent to this survey, a Phase II testing program should be considered. This testing program would be directed towards accelerated testing in order to predict long term degradation rates. Two and one half years and about $450,000 would be required to carry out this study.

It is our recommendation that Phase II should proceed but that the details of the program be finalized only after completion of an expanded survey of industrial users of flexible liners.

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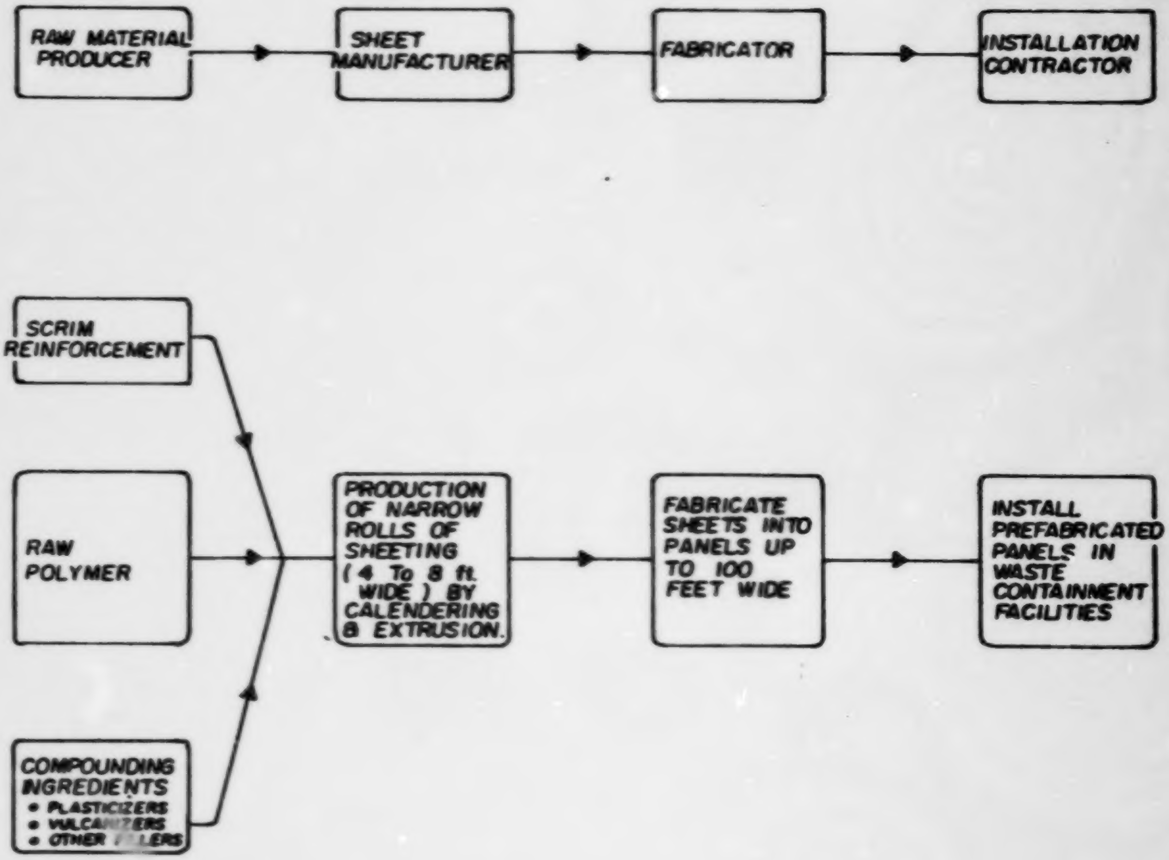
STRUCTURE OF POLYMERIC LINER INDUSTRY

FIGURE 1.


RAW MATERIAL PRODUCER
SHEET MANUFACTURER
FABRICATOR
INSTALLATION CONTRACTOR
SCRIM REINFORCEMENT
RAW POLYMER
COMPOUNDING INGREDIENTS
• PLASTICIZERS
• VULCANIZERS
• OTHER FILLERS
PRODUCTION OF NARROW ROLLS OF SHEETING (4 To 8 ft. WIDE) BY CALENDERING & EXTRUSION.
FABRICATE SHEETS INTO PANELS UP TO 100 FEET WIDE
INSTALL PREFABRICATED PANELS IN WASTE CONTAINMENT FACILITIES

Date JUNE 8, 1981.
Project No. 841-3015

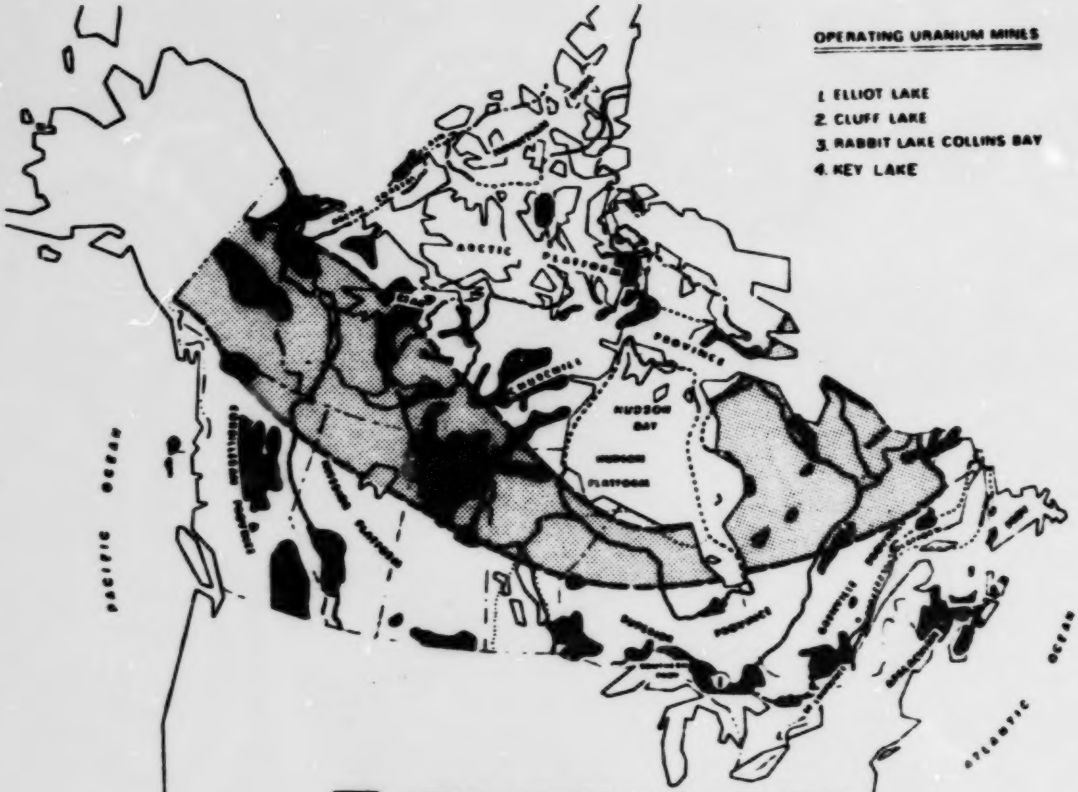
Golder Associates

Drawn C.M.S.
Chkd

Form G.A-0-4

AREAS IN CANADA FAVOURABLE FOR THE OCCURRENCE OF URANIUM DEPOSITS

FIGURE 2.


ARCTIC
PLATFORM
PROVINCE
CHURCHILL
HUDSON BAY
PLATFORM
PACIFIC OCEAN
ATLANTIC OCEAN

OPERATING URANIUM MINES

1. ELLIOT LAKE
2. CLUFF LAKE
3. RABBIT LAKE COLLINS BAY
4. KEY LAKE

■ AREAS FAVOURABLE FOR OCCURANCE OF URANIUM DEPOSITS

▨ DISCONTINUOUS PERMAFROST.

(AREA TO NORTH OF SHADING IS CONTINOUS PERMAFROST)

NOTE :
FOR DRAWING REFERENCE SEE REFERENCE No. 58 IN TEXT OF REPORT.

Date APRIL 24, 1984
Project 841-3015

Golder Associates

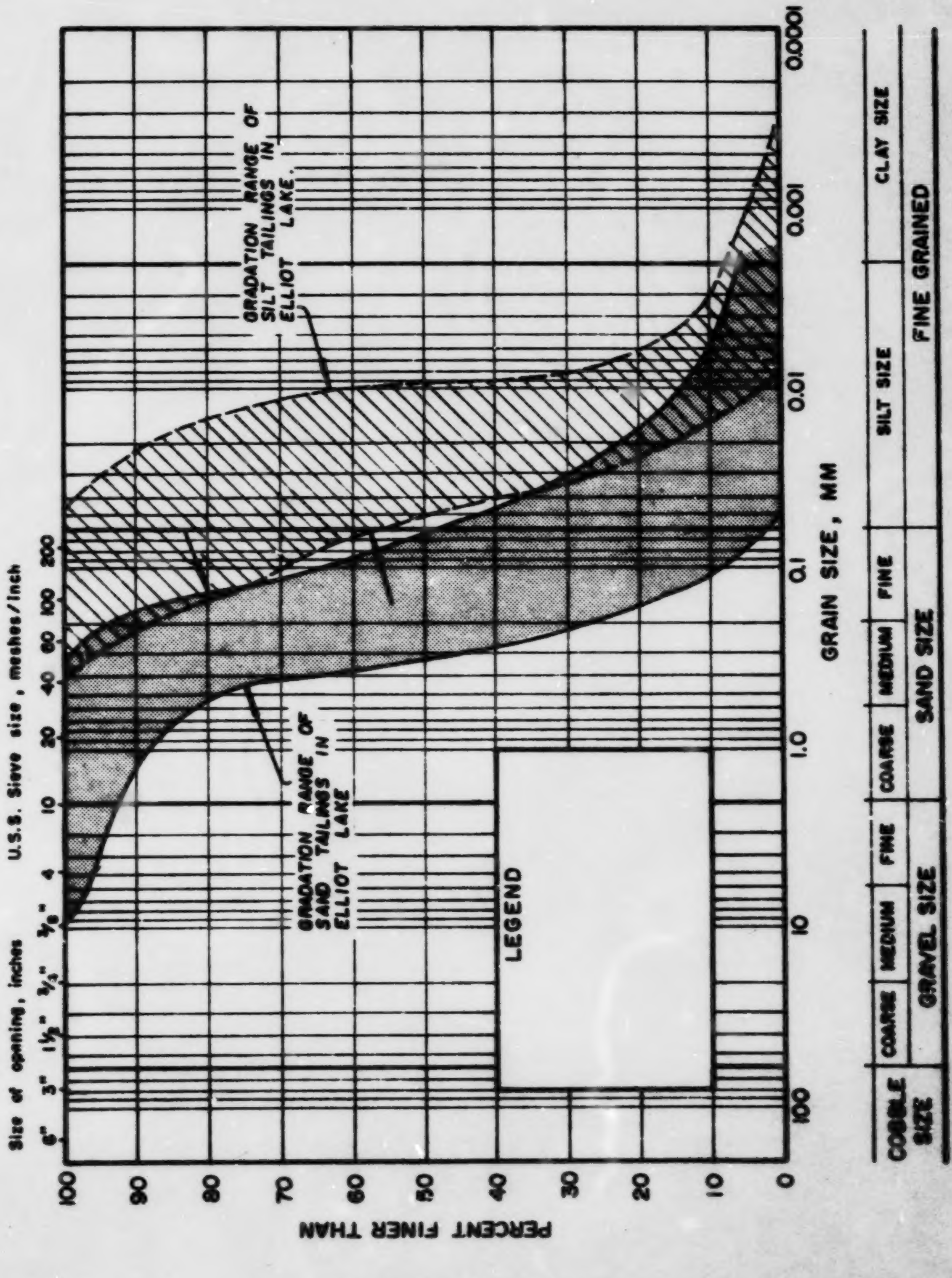
Drawn C.M.S.
Chkd

PROJ No. 841-3015

GRAIN SIZE DISTRIBUTION

ELLIOT LAKE TAILINGS

FIGURE 3



Form G.A.-D-6

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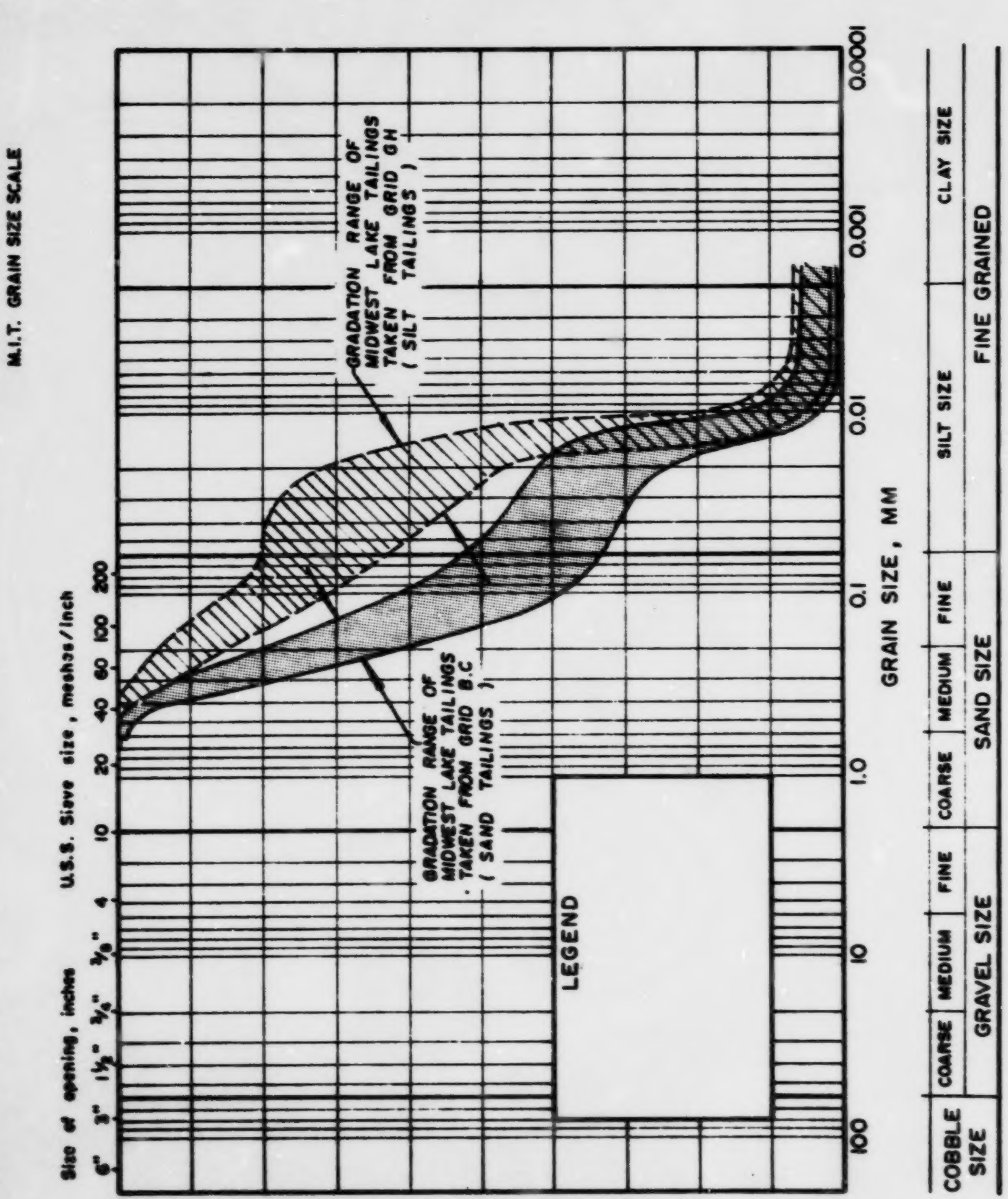
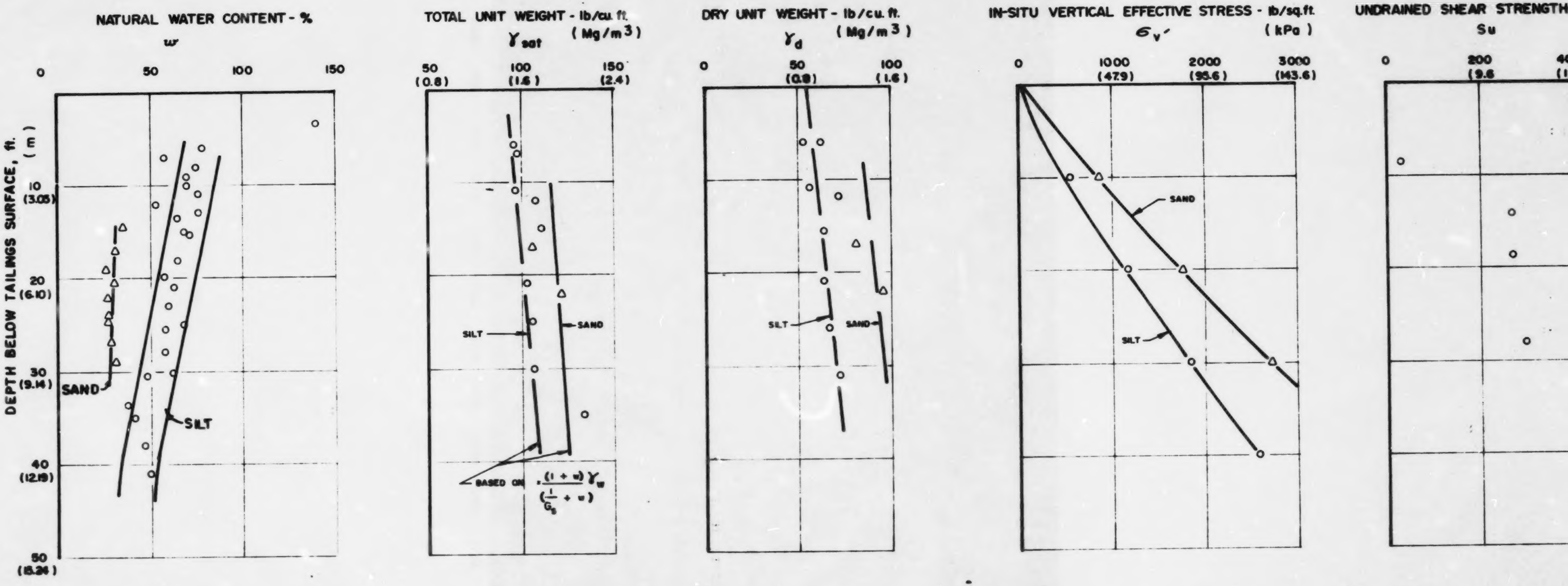
GRAIN SIZE DISTRIBUTION

MIDWEST LAKE TAILINGS

FIGURE 4



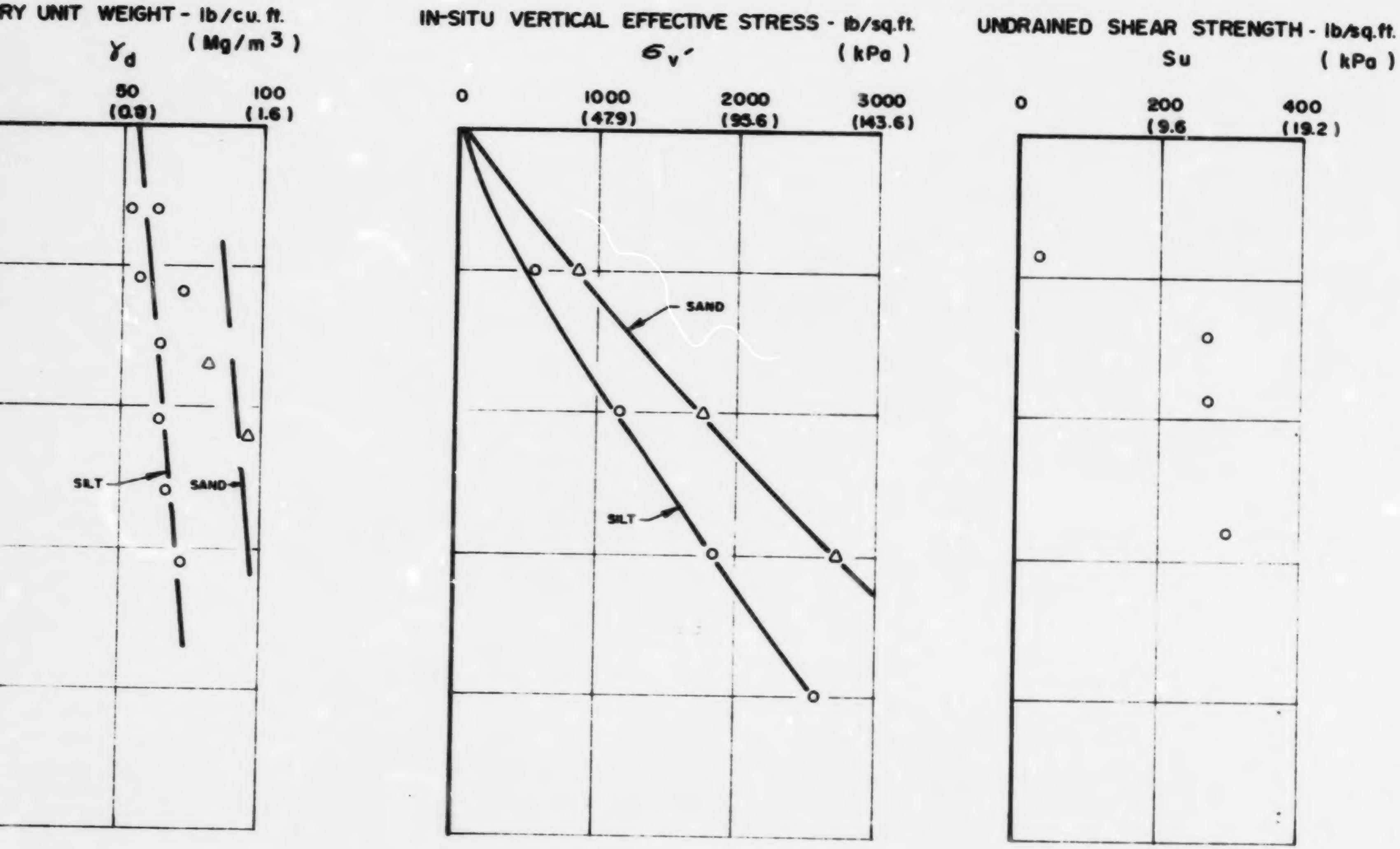
Golder Associates


NATURAL WATER CONTENT - %
w
0
50
100
150
DEPTH BELOW TAILINGS SURFACE, ft. (m)
10 (3.05)
20 (6.10)
30 (9.14)
40 (12.19)
50 (15.24)
SAND
SILT
TOTAL UNIT WEIGHT - lb/cu. ft. (Mg/m3)
γsat
50 (0.8)
100 (1.6)
150 (2.4)
SILT
SAND
BASED ON = (1 + w) γw / (1/Gs + w)
DRY UNIT WEIGHT - lb/cu. ft. (Mg/m3)
γd
0
50 (0.8)
100 (1.6)
SILT
SAND
IN-SITU VERTICAL EFFECTIVE STRESS - lb/sq. ft. (kPa)
σv'
0
1000 (47.9)
2000 (95.6)
3000 (143.6)
SAND
SILT
UNDRAINED SHEAR STRENGTH
Su
0
200 (9.6)

SILT AND SAND TAILINGS

DENISON TAILINGS AREA, ELLIOT LAKE

FIGURE 5.



Date APRIL 13,1982

Project 791231

Golder Associates

Drawn

Chkd

PROJECT DESCRIPTION		CATEGORY I URANIUM MINING INDUSTRY									CATEGORY II CANADIAN MINING INDUSTRY				
OWNER		COTTER CORPORATION	MINERALS EXPLORATION	DENISON MINES	DAWN MINING CO.	RIO ALGOM	DENISON MINES	WESTERN NUCLEAR INC.			INCO	FALCONBRIDGE MINES	POTASH CORP. OF SASK.	CENTRAL CANADA POTASH	POTASH CORP. OF SASK.
DESIGNER		WAHLER ASSOCIATES	DAMES & MOORE	GOLDER ASSOCIATES		GOLDER ASSOCIATES	GOLDER ASSOCIATES	DRAVO ENGINEERS			INCO ENGINEERING	GEOCON	B.B. TORCHINSKY	KILBORN LTD	PCS DESIGN ENGINEERING
LOCATION		CANON CITY COLARADO	SWEETWATER CO., WYOMING	DAM No. 1. WILLIAMS LAKE ONTARIO	FORD WASHINGTON	PANEL MINE & STRIKE LAKE ELLIOT LAKE ONT.	DAM No. 10 ELLIOT LAKE ONT.	SPOKANE INDIAN RESERVATION WASHINGTON			COPPER CLIFF ONTARIO	FALCONBRIDGE ONTARIO	COREY MINE SASKATCHEWAN	COLONSAY SASKATCHEWAN	ROCANVILLE
DATE OF INSTALLATION		1978	1980	1979	1981	1978 & 1979	1971-1972	1977			1977	1978	1976	1981 - 1982	1982-1983
DIMENSIONS	- AREA	607,000 m^2	243,000 m^2	2,600 m^2 LINER	113,000 m^2	53,000 m^2 (6 INSTALLATIONS)	TAILINGS POND 75 HECTARES LINER 9300 m^2	364,000 m^2			3500 m^2	6600 m^2	5000 m^2	SMALL STRIP DYKES	80000 m^2
	- DEPTH	30 m	30 m.		20 m.	21 m. max.	25 m. ULTIMATELY 38 m.	20 m			1 m.	8 m	5 m		5 m.
LINER	- TYPE	HYPALON	HYPALON SLOPES PVC BOTTOM	OIL RESISTANT PVC	HDPE	HYPALON	HYPALON	HYPALON			CPE	PVC	HYPALON	HYPALON, CPE	HDPE
	- THICKNESS	36,45 & 60 mil	30 mil, 20 mil	45 mils	30 mil	30 mil & 45 mil	30 mil	30 mil			30 mil	30 mil	30 mil	30 mil	30 mil BOTTOM 60 mil SLOPES
	- REINFORCEMENT	YES	NO	NO	NO	NO	NO	YES			NO		NO	NO	NO
	- FABRICATOR	WATERSAVER CO.	WATERSAVER CO.	SYNFLEX INDUSTRIES	GUNDLE PLASTICS	DUNLINE, SYNFLEX	DUNLINE, SYNFLEX	B.F. GOODRICH				STAFF INDUSTRIES	DUNLINE	DUNLOP, SYNFLEX	GUNDLE PLASTICS
	- INSTALLER	STAFFORD CONSTRUCTION	CRESTLINE SUPPLY		UNIVERSAL LININGS	ROMM CONSTRUCTION	REEMA TIP TOP, DENISON STAFF	B.F. GOODRICH				PITTS ENG. & CONSTRUCTION	DUNLINE	BRODSKY & SYNFLEX	SYNFLEX INC.
	- SOIL COVER	600 - 900 mm ON SLOPES	NONE	300 mm SAND	600 mm. SAND	600 mm SAND		300 mm SAND			300 mm OF 50 mm CRUSHED STONE	300 mm SAND 300 mm SLAG	NONE	300 mm. SAND	NONE
ATERIAL /WASTE RETAINED	- NATURE	URANIUM MILL TAILINGS	URANIUM MILL TAILINGS	URANIUM TAILINGS	URANIUM TAILINGS	URANIUM TAILINGS	URANIUM TAILINGS	URANIUM MILL TAILINGS			COPPER TAILINGS SEEPAGE WATER	COPPER TAILINGS	BRINE	SALT & BRINE	BRINE
	- SIZE	SILT	SAND SLURRY			SILT	SILT	FINE SAND			SUSPENDED SOLIDS			SAND TO CLAY	
	- WATER CONTENT	30% SOLIDS					50 - 80 % SOLIDS	45-50% SOLIDS			50 mg / LITRE				
	- PH	2 - 4	>2		1.8			5 - 9			3 : 1				
FOUNDING CONDITIONS		450 mm CLAY OVER ROCK		300 mm SAND	150 mm SAND	600 mm SAND	GRANULAR	SAND			CLAY	CLAY	COMPACTED TILL	150 mm. SAND OVER TILL	150 mm SAND
NSTALLATION PROBLEMS		NONE NOTED	WIND & WAVE DAMAGE		SAND COVER SLIDING ON 3:1 SLOPE	SEAMING DURING WET WEATHER	SLIPPING ON STEEP SLOPES	OCCASIONAL PUNCTURE					FASTENING LINER TO CONC.	NONE	DURING COLD, WET, OR WINDY WEATHER
PERFORMANCE	- SUCCESSFUL	YES	YES	YES	YES	YES	YES	YES			YES	YES	YES	YES	YES
	- PROBLEMS		WIND, WAVE & EQUIPMENT DAMAGE			PINHOLES REQ'D REPAIR	NONE KNOWN	NONE KNOWN					REMOVAL OF AIR BUBBLES		WELDING 30 mil SHT RECOMMENDS THICKER SHEET
ONITORING SYSTEM	- INSTALLED	YES	YES		YES	YES	YES	YES			NO	NO		YES	YES
	- RESULTS	NO PROBLEMS TO DATE	NO PROBLEMS TO DATE					NO PROBLEMS TO DATE							NO PROBLEMS TO DATE

CATEGORY III
OTHER INSTALLATIONS

	PUBLIC SERVICE COMPANY OF COLORADO	CHEVRON CANADA	ALLIED CHEMICAL	ALLIED CHEMICAL	U.S. BUREAU OF RECLAMATION	DOME PETROLEUM		
	STEARNS-ROGERS INC.	EBA ENGINEERING	ALLIED CHEMICAL	GIFFELS, CARR & DONALD	U.S.B.R.	KOMEX		
	PAWNEE STATION, BRUSH COLO.	FORT SASKATCHEWAN, ALBERTA.	AMHERSTBURG ONTARIO	AMHERSTBURG ONTARIO	MT. ELBERT, FORE-BAY, TWIN LAKES COLORADO	FORT SASKATCHEWAN ALBERTA.		
	1979 & 1980	1982	1981	1966 - 1977	1980	1981		
	8 PONDS 267,000 m ^{2}	42 000 m ^{2}	12,000 m ^{2}	50,000 m ^{2}	1,174,000 m ^{2}	30 000 m ^{2}		
	3.5 m.	10 m.	4.5 m	4.5 m	21 m.	7 m		
	HDPE	HDPE	ASPHALTIC CONCRETE	EPDM	CPE	PVC BOTTOM HYPALON SLOPES		
	80 mil	60 mil	75 mm.	50 - 63 mil	45 mil	20mil, 36 mil		
	NO	NO		NO	YES	PVC NO HYPALON YES		
	SCHLEGEL	SCHLEGEL	AAPCO ASPHALTING	U.S. RUBBER UNIROYAL		SYNFLEX		
	SCHLEGEL	SCHLEGEL	E. BONDY TRUCKING	WATER GUIDANCE SYSTEMS, LEXSUCO CANADA.		SYNFLEX		
	300 mm SAND	NONE			150 mm PROCESSED EARTH	300 mm SAND		
	BOTTOM ASH	BRINE	LIQUID CALCIUM CHLORIDE	LIQUID CALCIUM CHLORIDE	WATER (PUMPED STORAGE)	BRINE		
	5 - 11							
	600 mm CLAY	SAND OVER CLAY	150mm CRUSHED GRANULAR	CLAY	150mm PROCESSED EARTH	SAND OR GEOTEXTILE		
	NONE	GOOD WEATHER NECESSARY	COMPACTION ON SLOPES			DEWATERING		
	YES	YES	YES	NO	YES	YES		
	NONE	NONE	CRACKING SEALED BY SPRAYING	SEAM DETERIORATION AND LOSS OF PLASTICIZER		BLISTERS ON HYPALON		
	YES	YES	NO	NO	YES	YES		
	NO EVIDENCE OF LEAKAGE	INCONCLUSIVE			FAVOURABLE	INCONCLUSIVE		

RESULTS OF INDUSTRY SURVEY OF FLEXIBLE LINER USERS

FIGURE 6

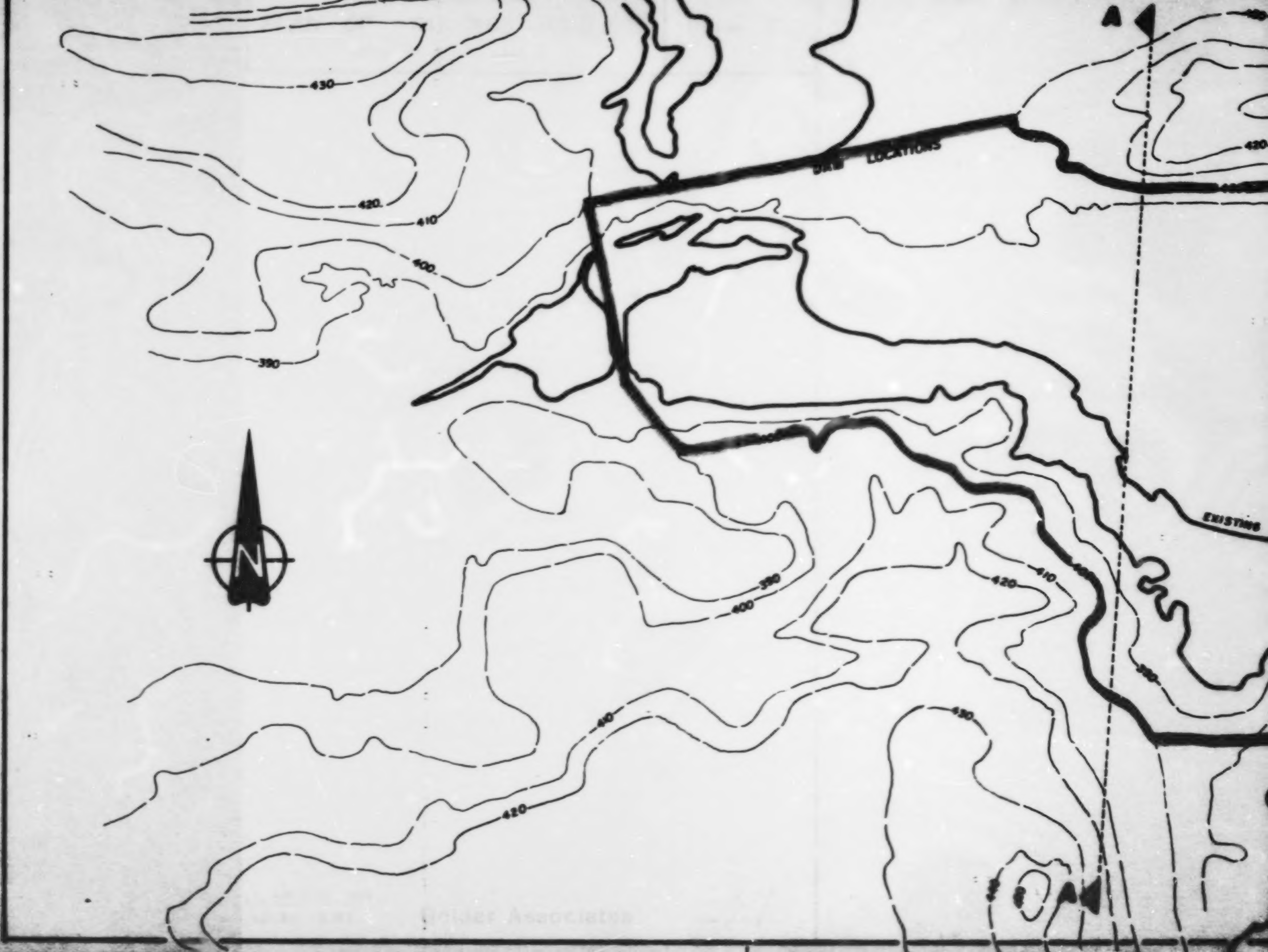
NOTES

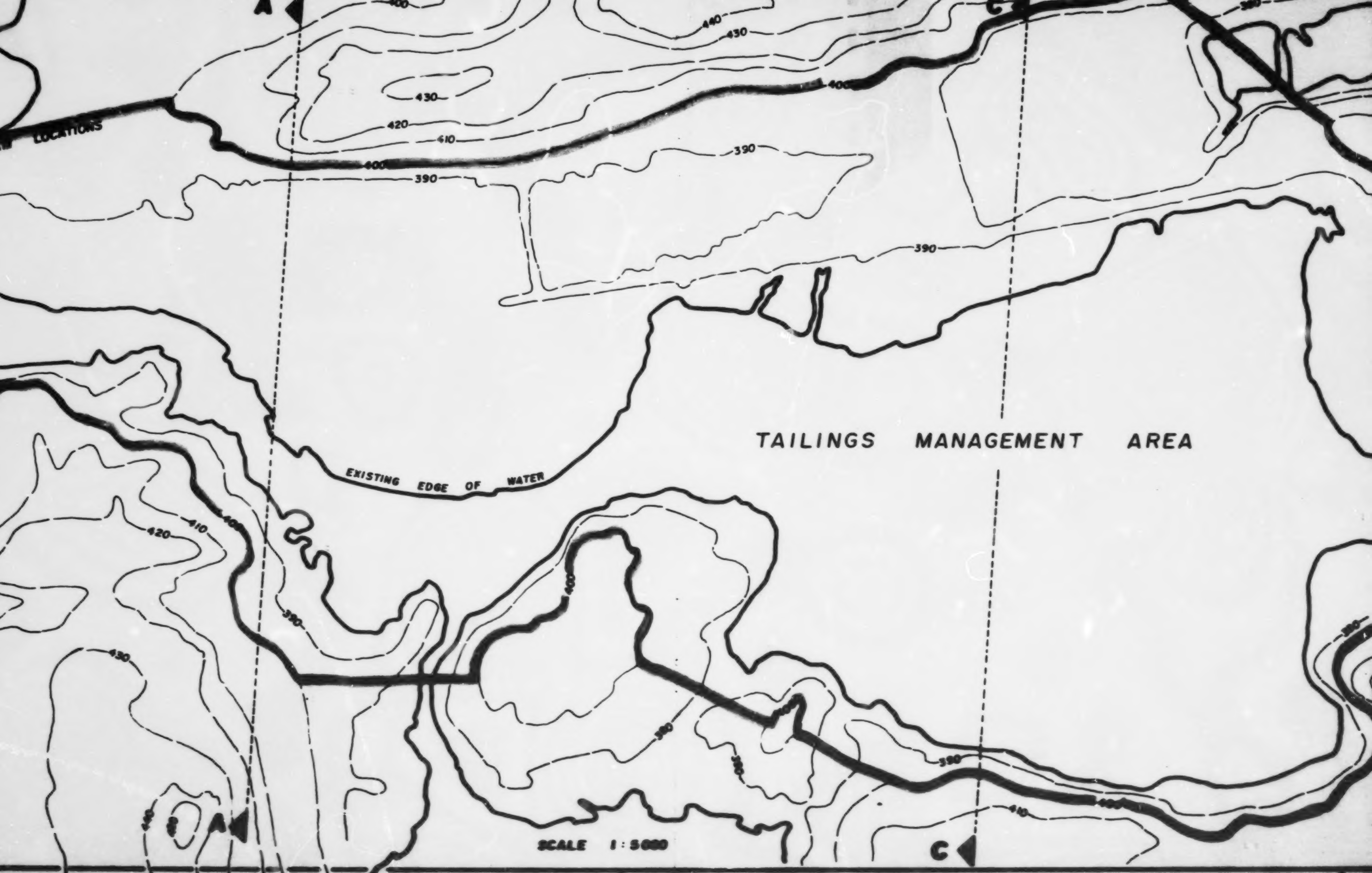
THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

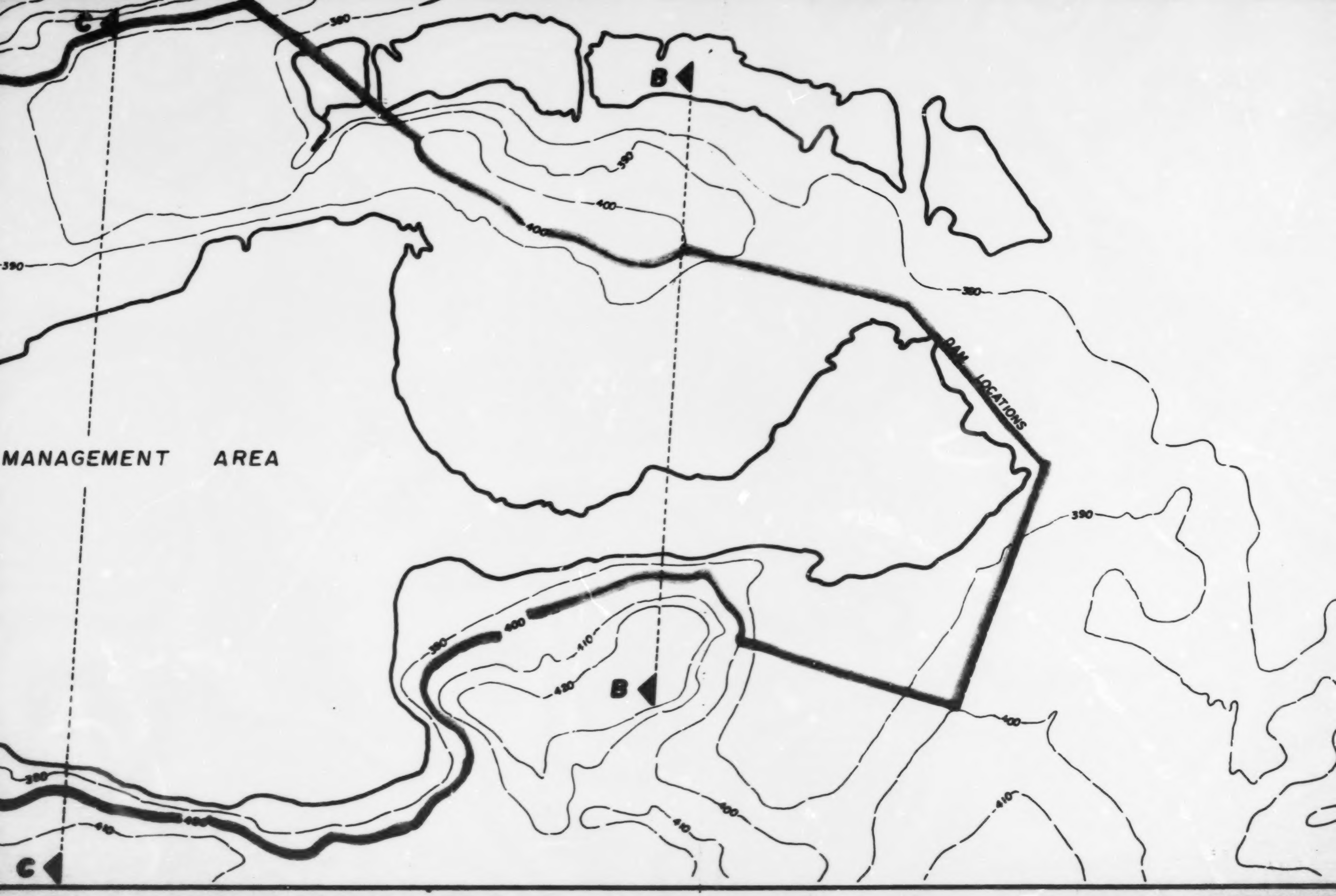
Date APRIL 25, 1984
Project 841-3015

Golder Associates

C.R.S.


A
430
420
410
400
390
DAM LOCATIONS
EXISTING
N
Golder Associates

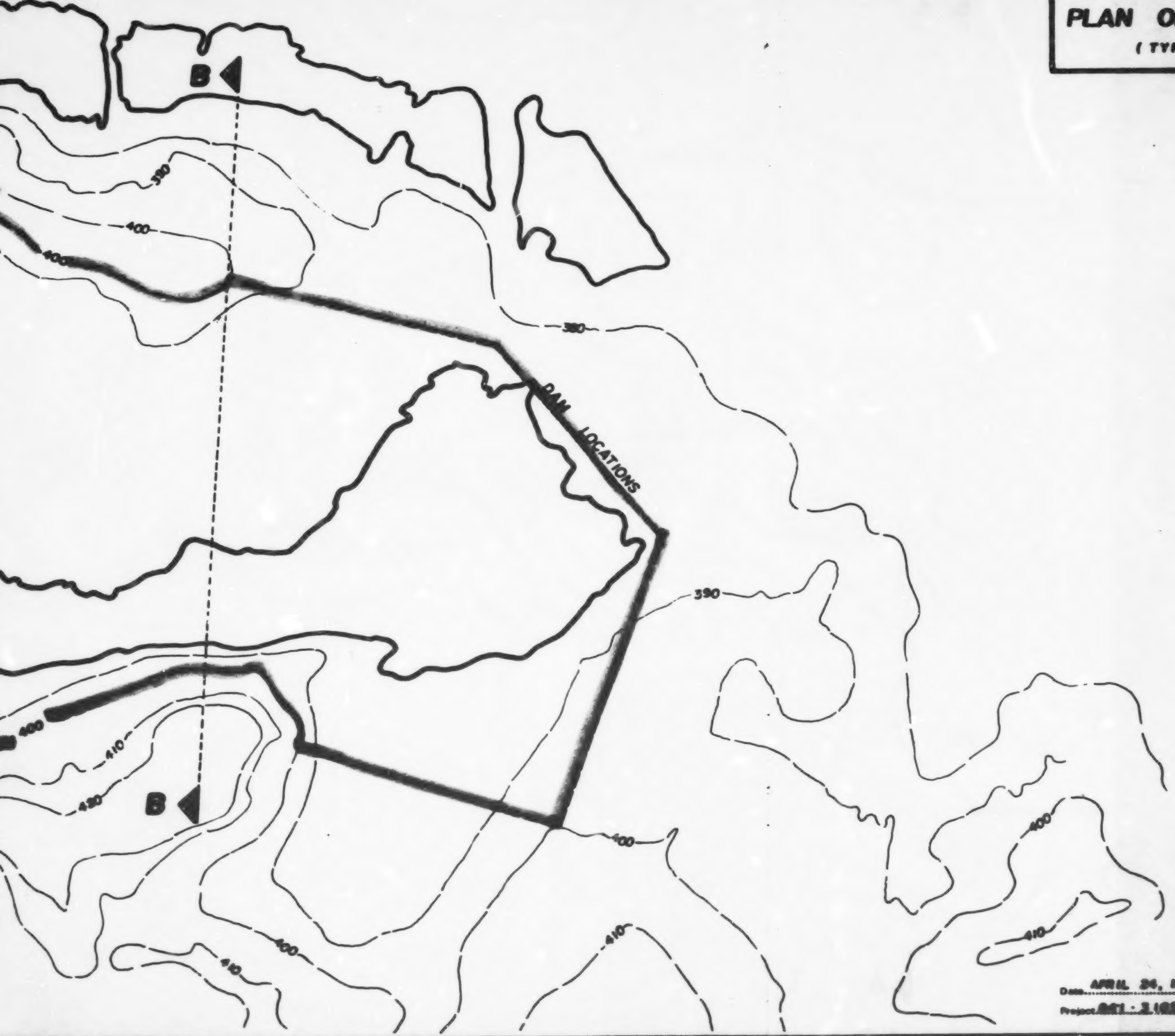

A
C
400
440
430
430
420
410
400
390
390
390
390
LOCATIONS
EXISTING EDGE OF WATER
TAILINGS MANAGEMENT AREA
420
410
400
400
390
430
380
390
390
400
410
400
390
440
400
A
SCALE 1:5000
C


C
380
B
390
390
400
400
390
380
DAM LOCATIONS
MANAGEMENT AREA
390
380
400
410
420
B
400
380
400
410
400
410
410
C

PLAN OF TAILINGS BASIN

(TYPICAL OF ELLIOT LAKE)

FIGURE 7


B
390
400
400
380
DAM LOCATIONS
390
400
410
420
B
400
400
410
410
400
410

NOTES

FOR SECTIONS REFER TO FIGURES 8, 9 & 10.

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

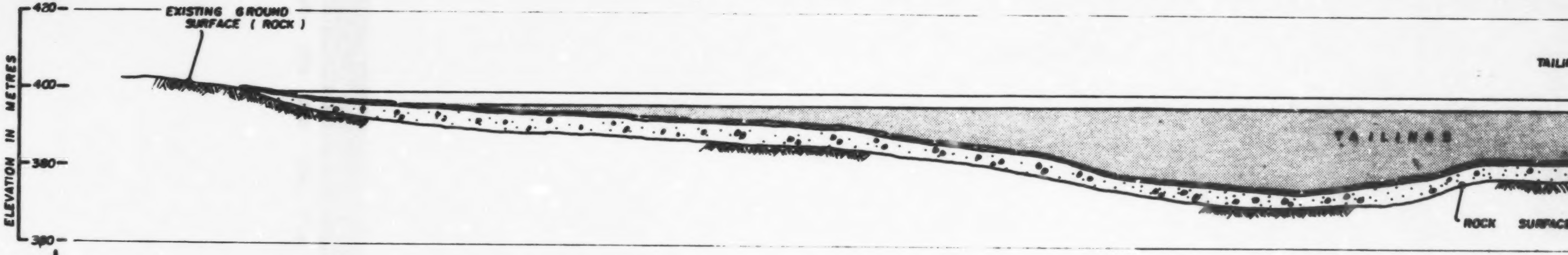
TAILINGS AT ELEVATION 400 m. ON CLOSE - OUT

Date APRIL 24, 1984

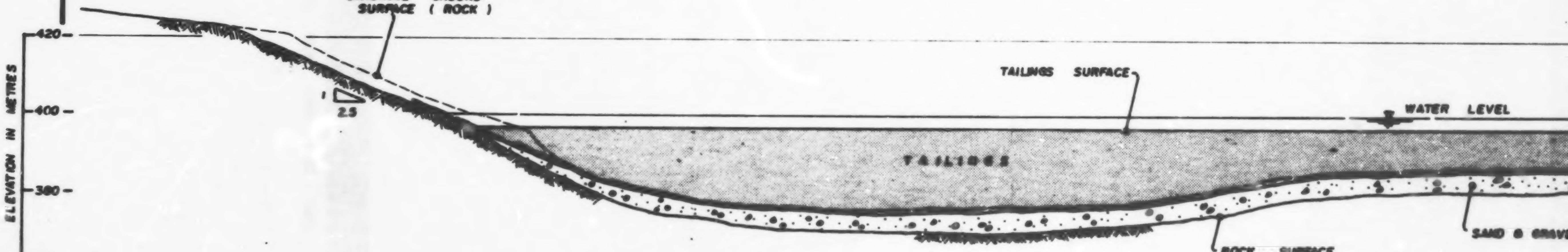
Project 841 - 3165

Golder Associates

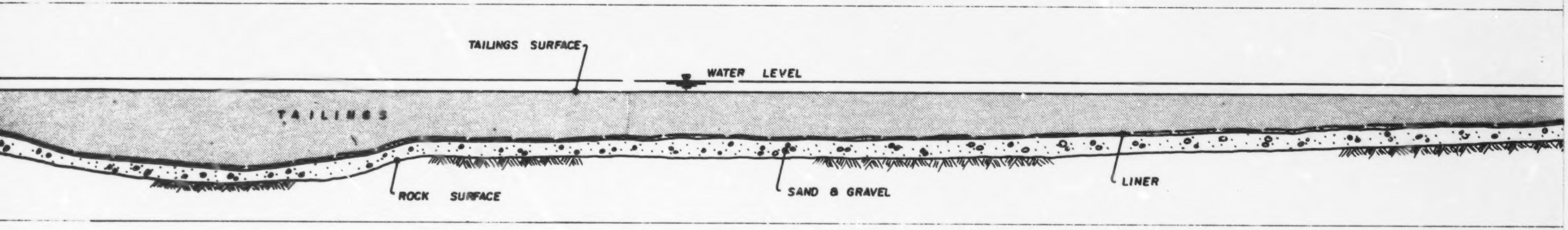
C.M.B.


420
400
380
360
ELEVATION IN METRES
EXISTING GROUND SURFACE (ROCK)
TAILI
TAILINGS
ROCK SURFACE

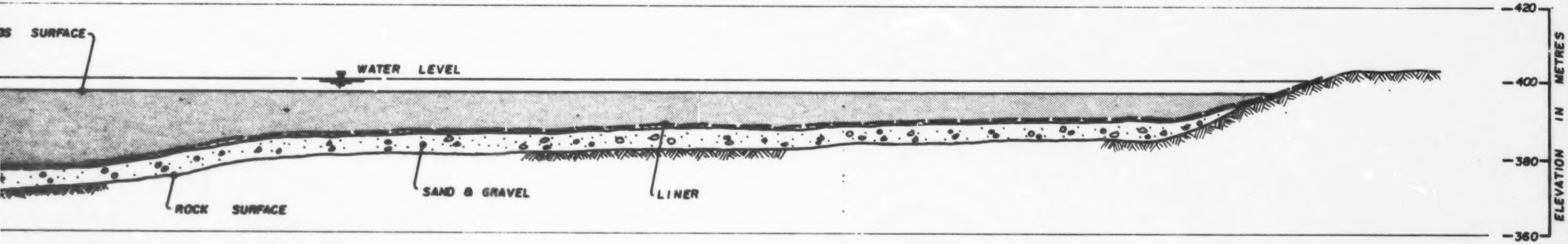
CROSS


420
400
380
360
ELEVATION IN METRES
ORIGINAL GROUND SURFACE (ROCK)
1
2.5
TAILINGS SURFACE
WATER LEVEL
TAILINGS
ROCK SURFACE
SAND & GRAVE

CROSS · SECTION B - B


TAILINGS SURFACE
WATER LEVEL
TAILINGS
ROCK SURFACE
SAND & GRAVEL
LINER

CROSS · SECTION A · A

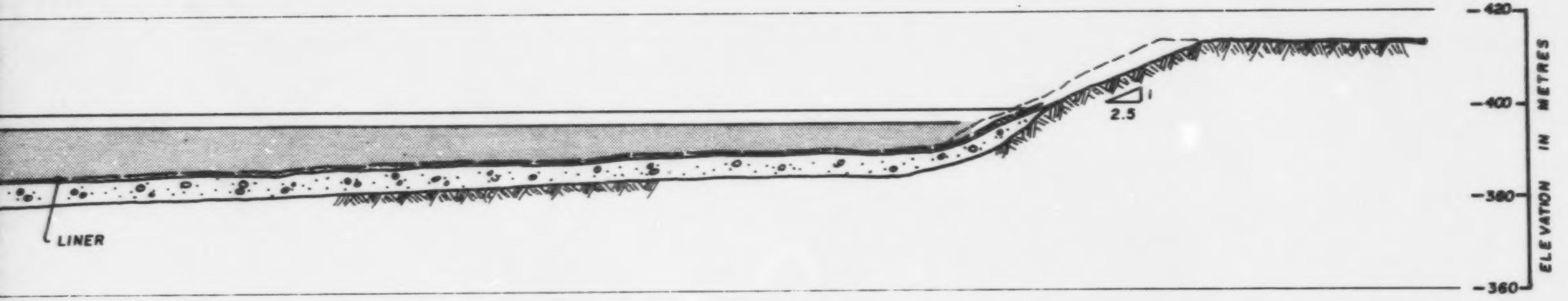

S SURFACE
WATER LEVEL
ROCK SURFACE
SAND & GRAVEL
LINER
420
400
380
360
ELEVATION IN METRES

CROSS · SECTION B - B

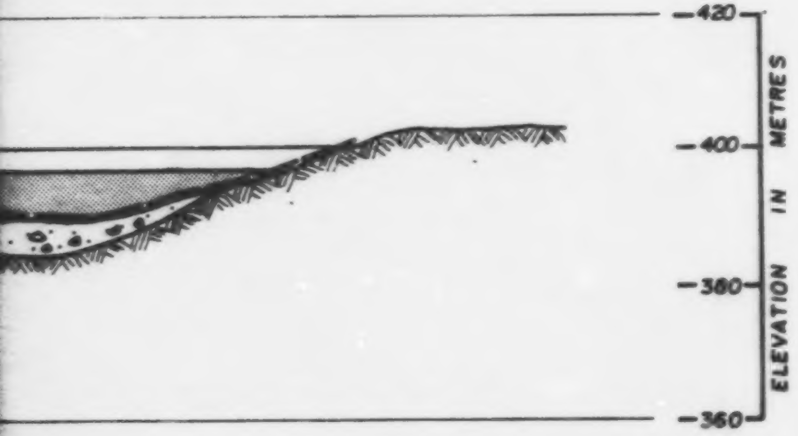
CROSS·SECTIONS A·A & B·B

(TYPICAL OF ELLIOT LAKE)

FIGURE 8.



420
400
380
360
ELEVATION IN METRES
1
2.5
LINER



420
400
380
360
ELEVATION IN METRES

NOTES

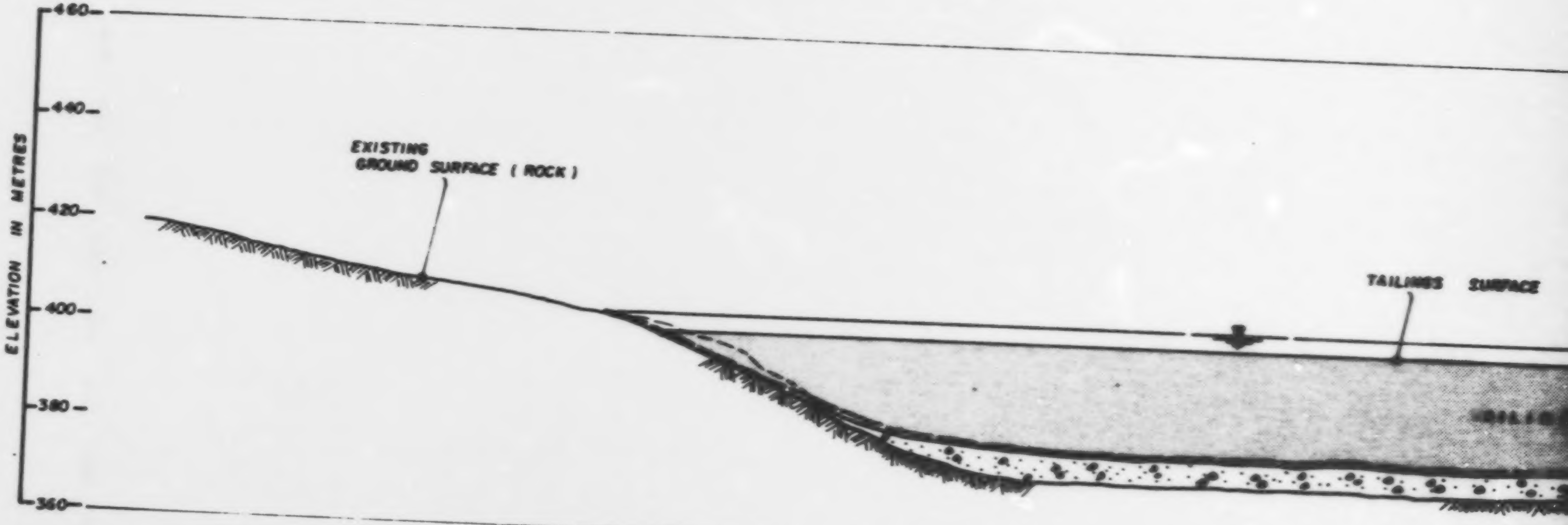
SECTION SCALES :
1 : 1000 - HORIZONTAL & VERTICAL.

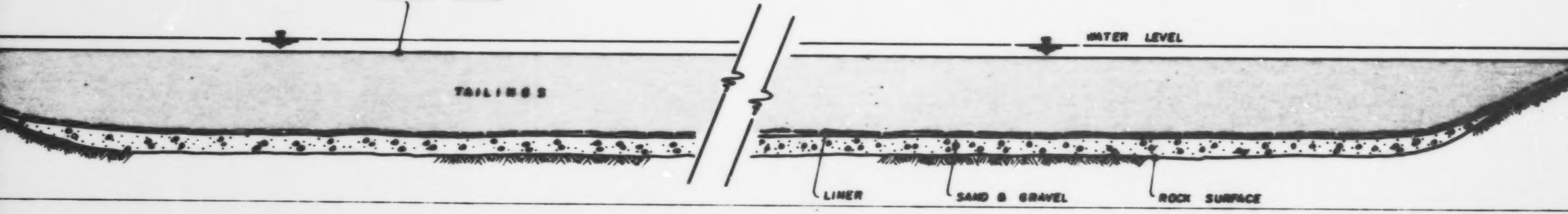
THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

Date APRIL 21, 1984
Project 841-3015

Golder Associates

Drawn C.M.S.
Chkd


ELEVATION IN METRES
EXISTING GROUND SURFACE (ROCK)
TAILINGS SURFACE


TAILINGS SURFACE
WATER LEVEL
TAILINGS
LINER
SAND & GRAVEL
ROCK SURFACE

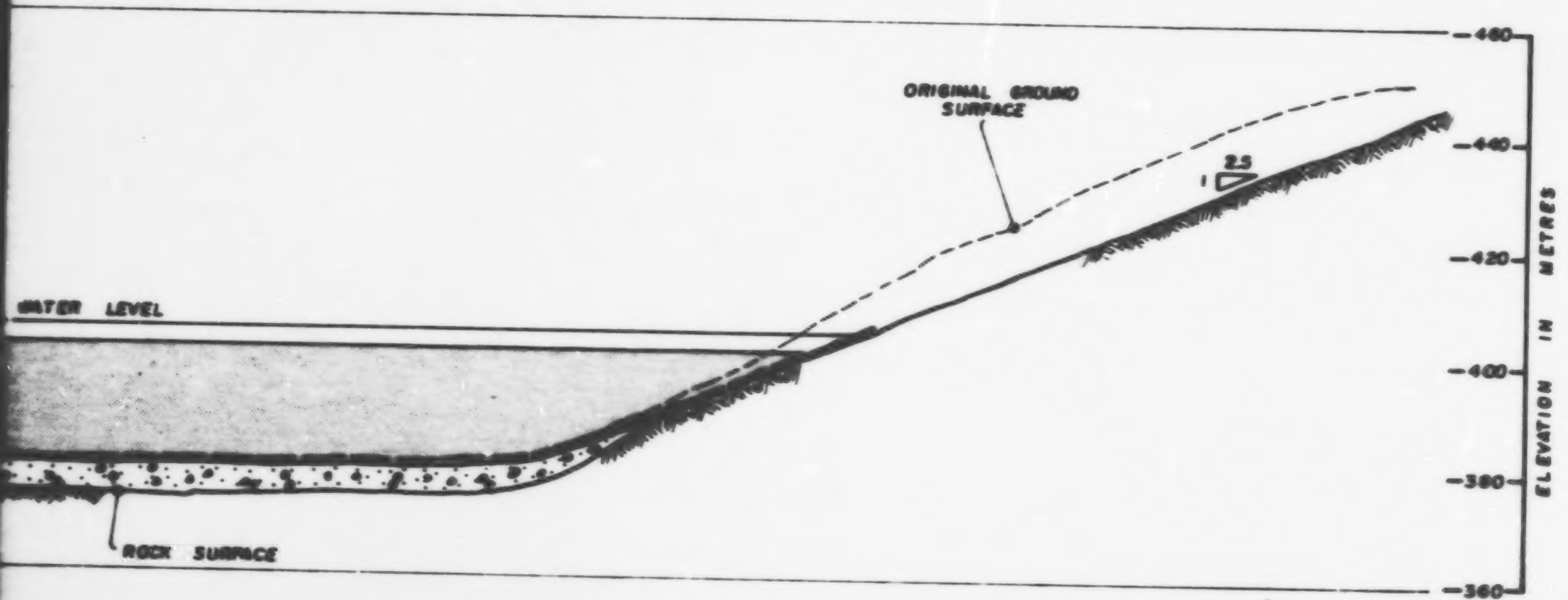
CROSS · SECTION C-C

SCALES - HORIZONTAL & VERTICAL 1:1000

CROSS · SECTION C·C

(TYPICAL OF ELLIOT LAKE)

FIGURE


ORIGINAL GROUND SURFACE
2.5
1
WATER LEVEL
ROCK SURFACE
460
440
420
400
380
360
ELEVATION IN METRES

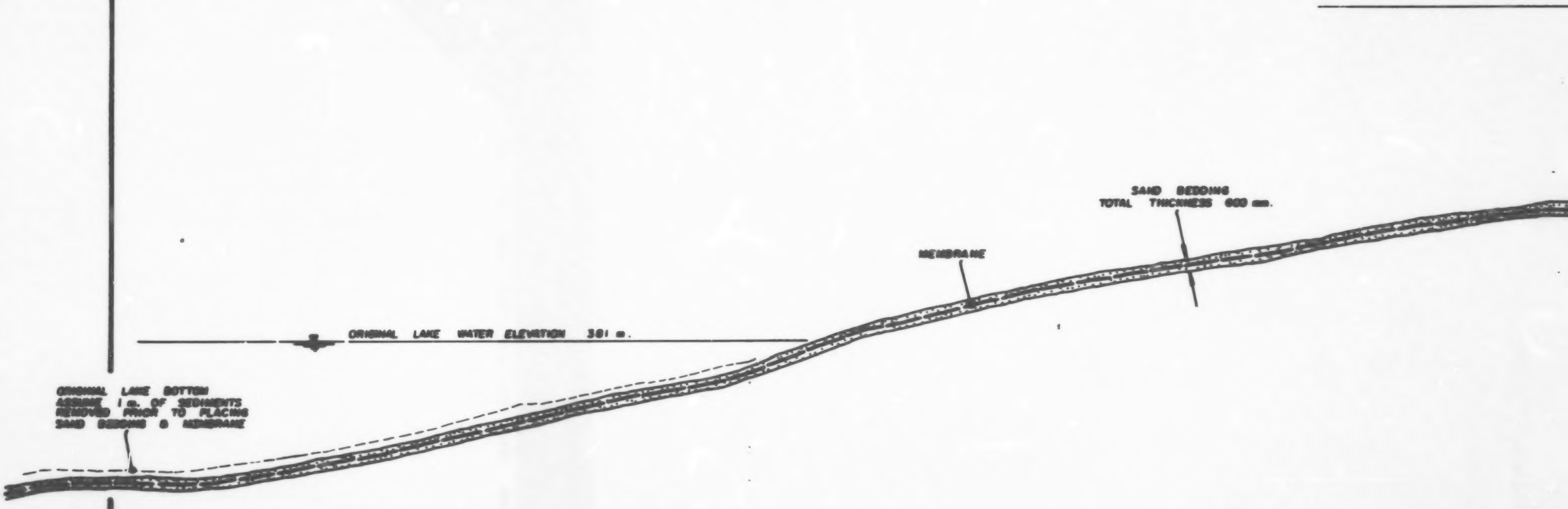
NOTES

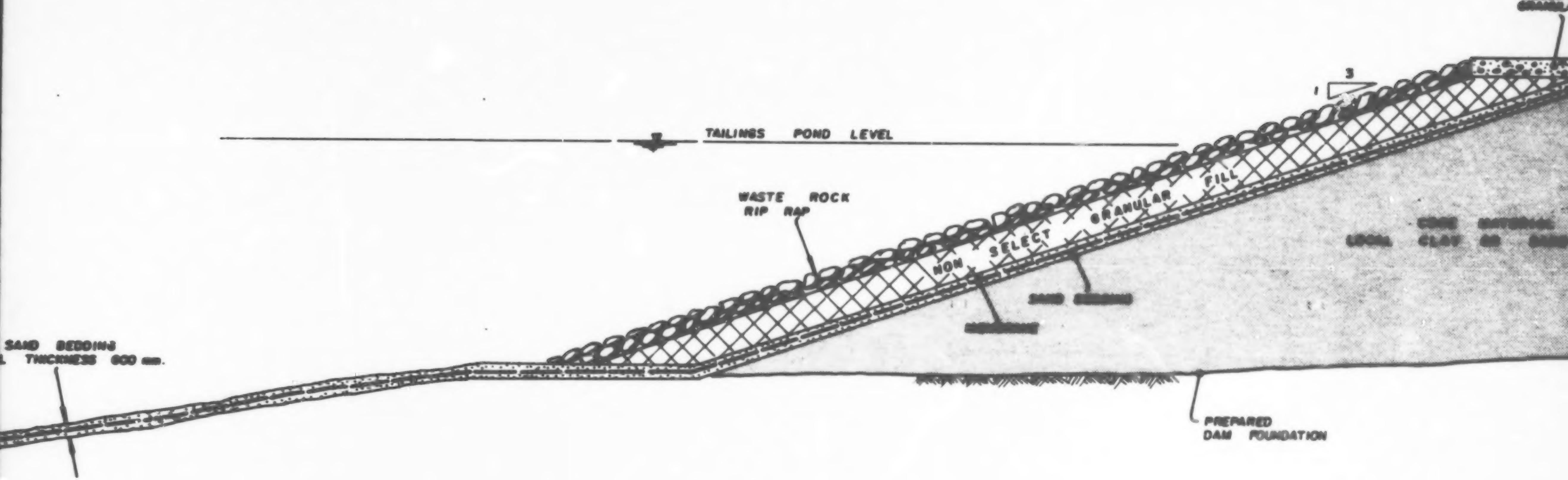
FOR SECTION LOCATION REFER TO FIGURE

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

Date APRIL 24, 1984
Project 841-3013

Golder Associates

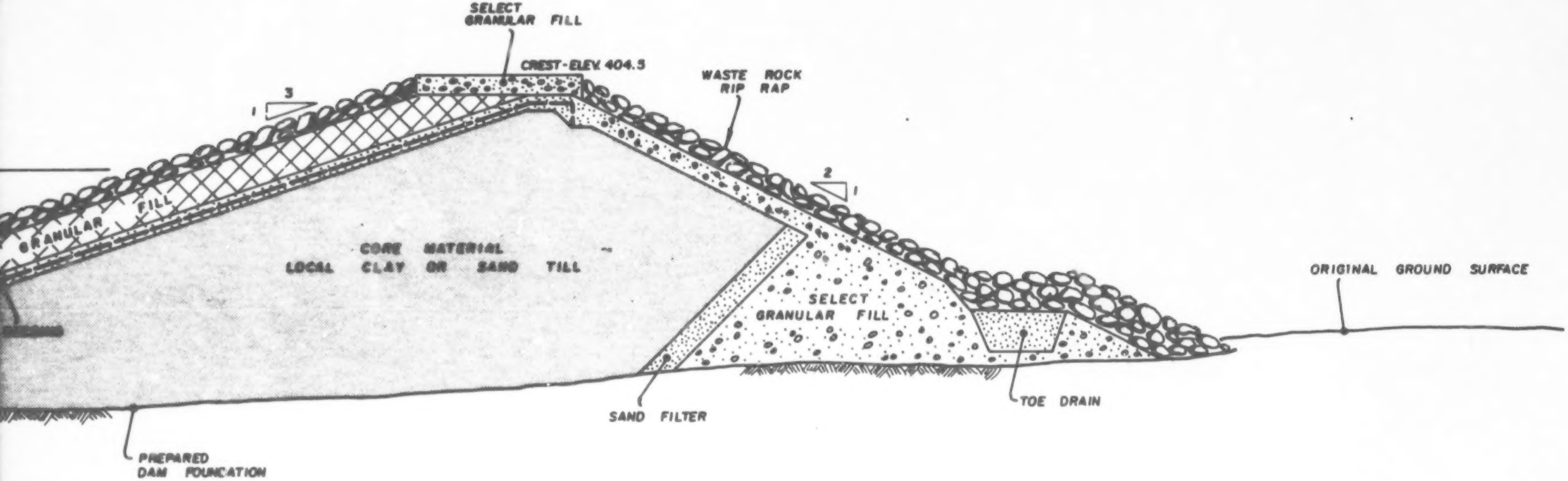

SAND BEDDING
TOTAL THICKNESS 600 mm.
MEMBRANE
ORIGINAL LAKE WATER ELEVATION 381 m.
ORIGINAL LAKE BOTTOM
ASSUME 1 m. OF SEDIMENTS
REMOVED PRIOR TO PLACING
SAND BEDDING & MEMBRANE


SELECT
GRANULA
3
1
TAILINGS POND LEVEL
WASTE ROCK
RIP RAP
NON SELECT GRANULAR FILL
CORE MATERIAL
LOCAL CLAY OR SAND
SAND BEDDING
SAND BEDDING
L THICKNESS 600 mm.
PREPARED
DAM FOUNDATION

SCHEMATIC ILLUSTRATION OF DAM SECTION

(TYPICAL OF ELLIOT LAKE)

FIGURE 10


SELECT GRANULAR FILL
CREST-ELEV. 404.5
WASTE ROCK RIP RAP
3
1
2
1
GRANULAR FILL
CORE MATERIAL
LOCAL CLAY OR SAND TILL
SELECT GRANULAR FILL
ORIGINAL GROUND SURFACE
SAND FILTER
TOE DRAIN
PREPARED DAM FOUNDATION

NOTES

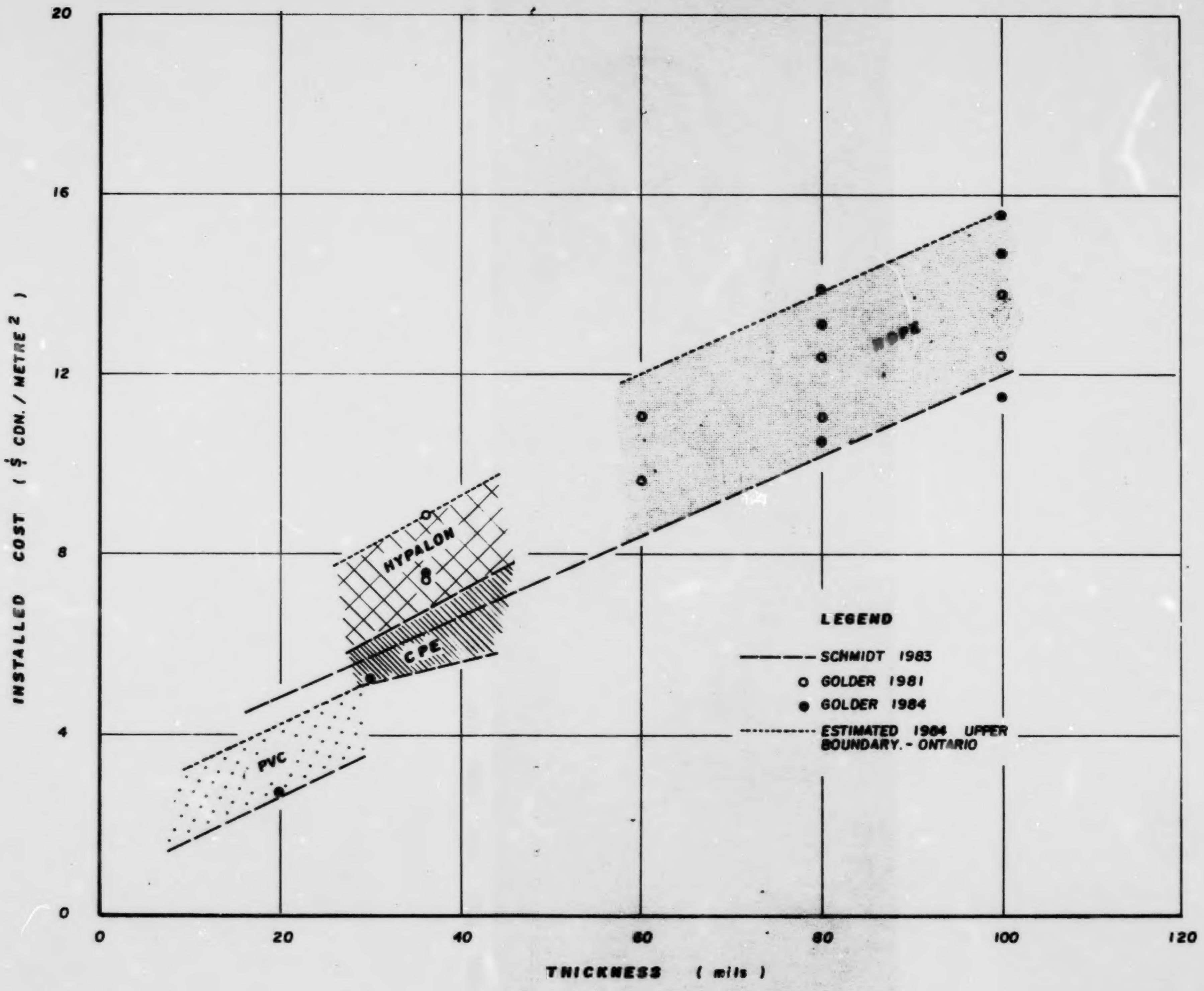
THIS DRAWING IS SCHEMATIC ONLY
- APPROXIMATE SCALE 1 : 200

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

Date APRIL 21, 1983
Project 841-3105

Golder Associates

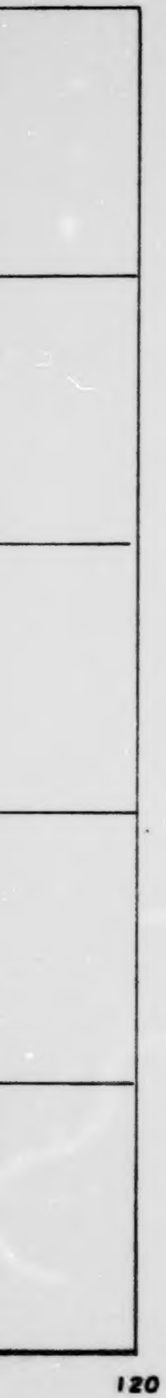
Drawn C.M.S.
Chkd



20
16
12
8
4
0
INSTALLED COST ($ CDN. / METRE²)
0
20
40
60
80
100
120
THICKNESS (mils)
PVC
HYPALON
CPE
HDPE
LEGEND
SCHMIDT 1983
○ GOLDER 1981
● GOLDER 1984
ESTIMATED 1984 UPPER BOUNDARY. - ONTARIO

INSTALLED COST OF
FLEXIBLE MEMBRANE LINERS

FIGURE **11.**



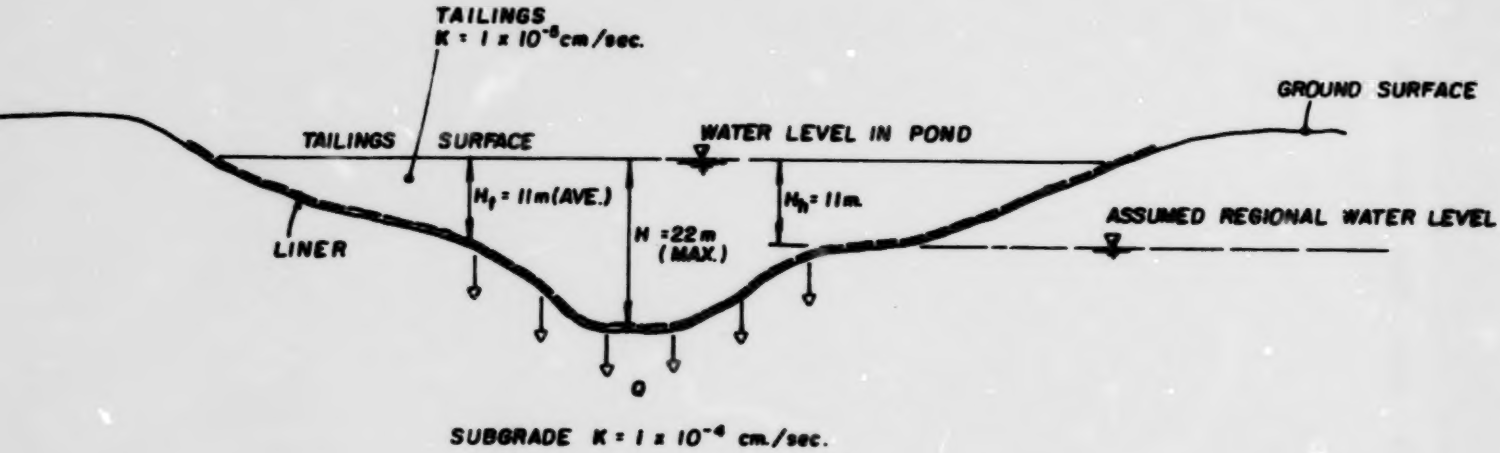
NOTES

1. THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.
2. COSTS ARE FOR SUPPLY AND INSTALLATION BUT DO NOT INCLUDE SITE PREPARATION, SOIL COVER, ETC.

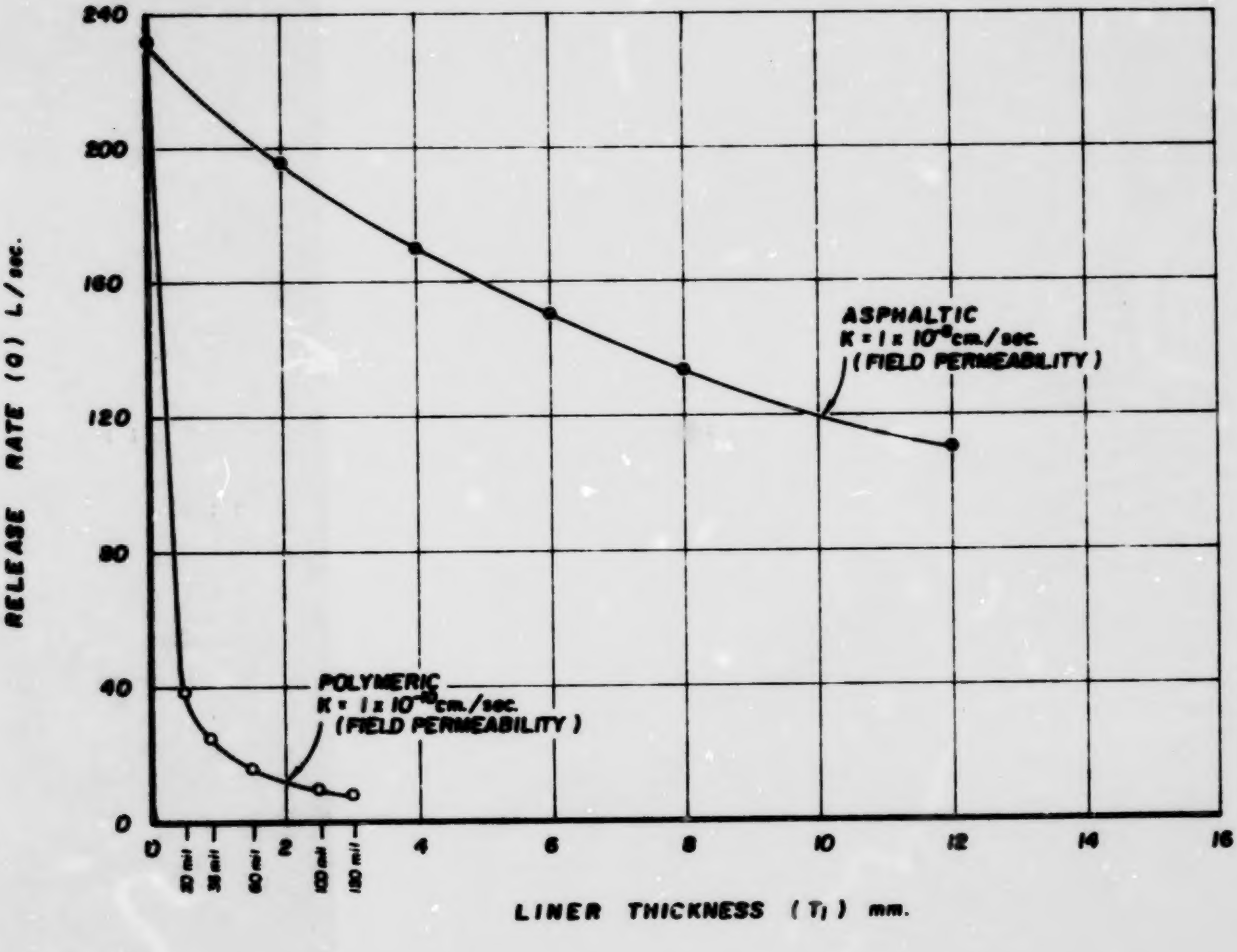
Date APRIL 26, 1984
Project 841-3015

Golder Associates

Drawn C.M.S.
Chkd


TAILINGS
K = 1 x 10^{-5} cm/sec.
GROUND SURFACE
TAILINGS SURFACE
WATER LEVEL IN POND
H_t = 11m (AVE.)
H = 22m (MAX.)
H_h = 11m.
ASSUMED REGIONAL WATER LEVEL
LINER
Q
SUBGRADE K = 1 x 10^{-4} cm./sec.

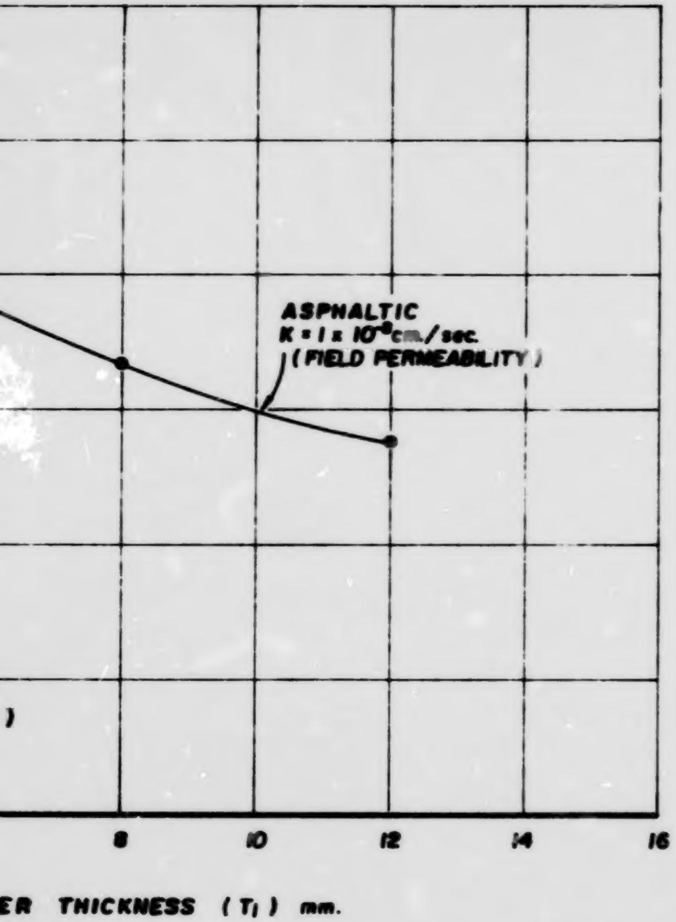
TAILINGS BASIN


RELEASE RATE (Q) L/sec.
240
200
160
120
80
40
0
0
20 mil
36 mil
60 mil
2
100 mil
120 mil
4
6
8
10
12
14
16
LINER THICKNESS (T_l) mm.
ASPHALTIC
K = 1 x 10^{-8} cm./sec.
(FIELD PERMEABILITY)
POLYMERIC
K = 1 x 10^{-10} cm./sec.
(FIELD PERMEABILITY)

ESTIMATED RELEASE RATES FOR POLYMERIC, & ASPHALTIC LINERS

(TYPICAL OF ELLIOT LAKE)

FIGURE **12**



NOTES

$$Q = \frac{H_h}{\frac{H_t}{K_t} + \frac{T_l}{K_l}} \times A$$

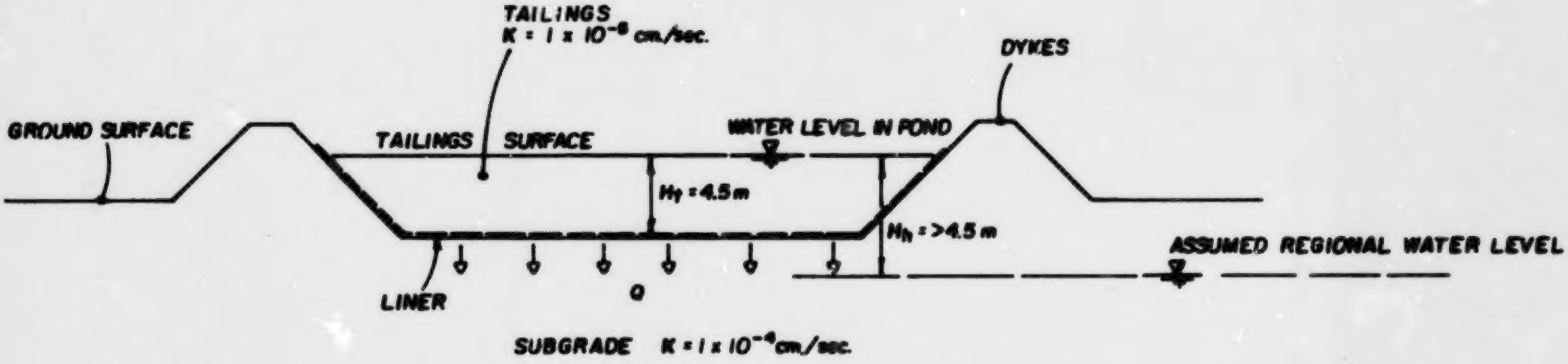
H_h = PIEZOMETRIC HEAD
H_t = HEIGHT OF TAILINGS (AVERAGE)
T_l = THICKNESS OF LINER
K_t = PERMEABILITY OF TAILINGS
K_l = PERMEABILITY OF LINER
A = AREA OF POND (232 HECTARES)

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

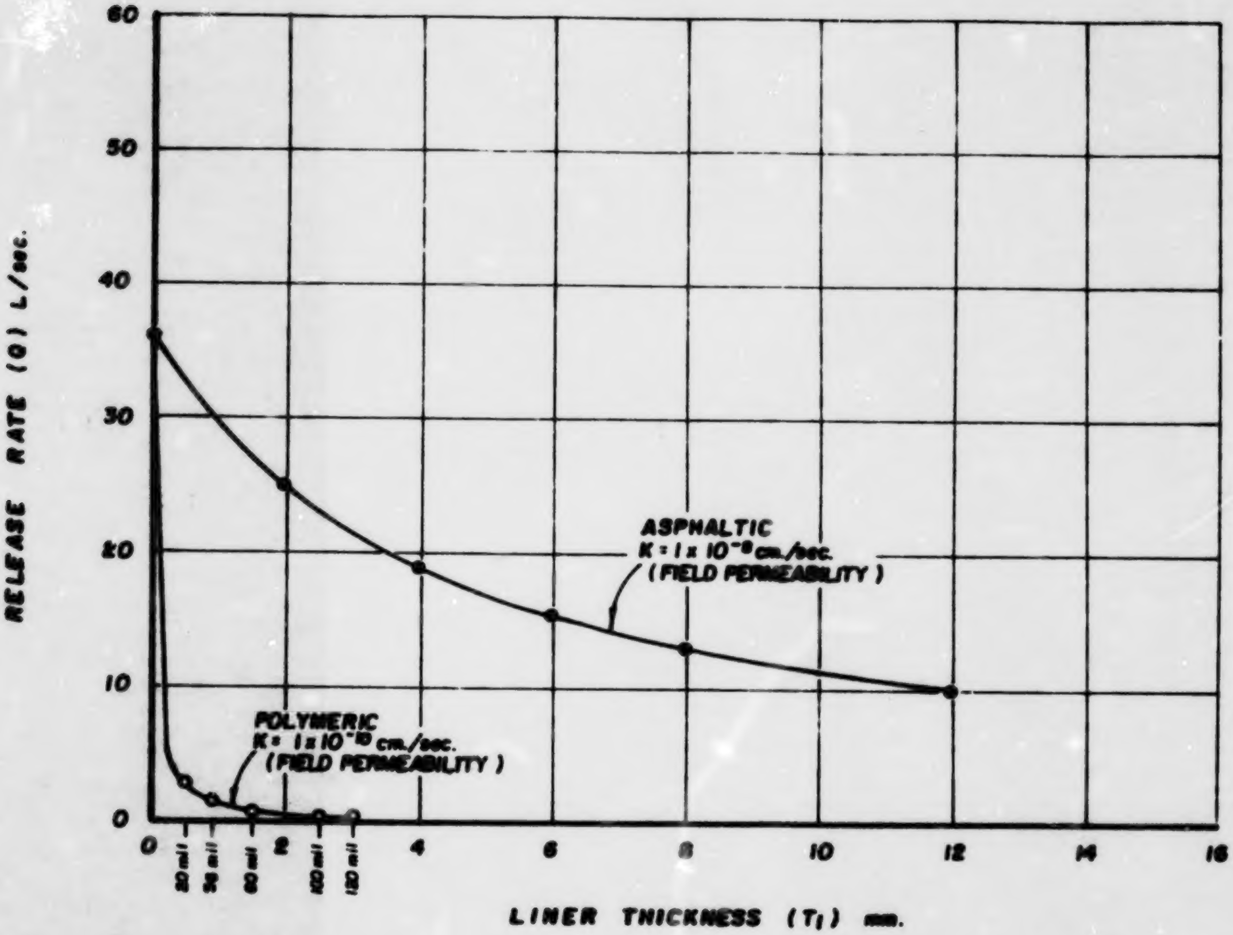
Date JULY 18, 1984
Project 841-3015

Golder Associates

Drawn W.D.F.
Chkd


TAILINGS
K = 1 x 10^{-6} cm./sec.
DYKES
GROUND SURFACE
TAILINGS SURFACE
WATER LEVEL IN POND
H_t = 4.5m
H_h = >4.5 m
ASSUMED REGIONAL WATER LEVEL
LINER
Q
SUBGRADE K = 1 x 10^{-4} cm./sec.

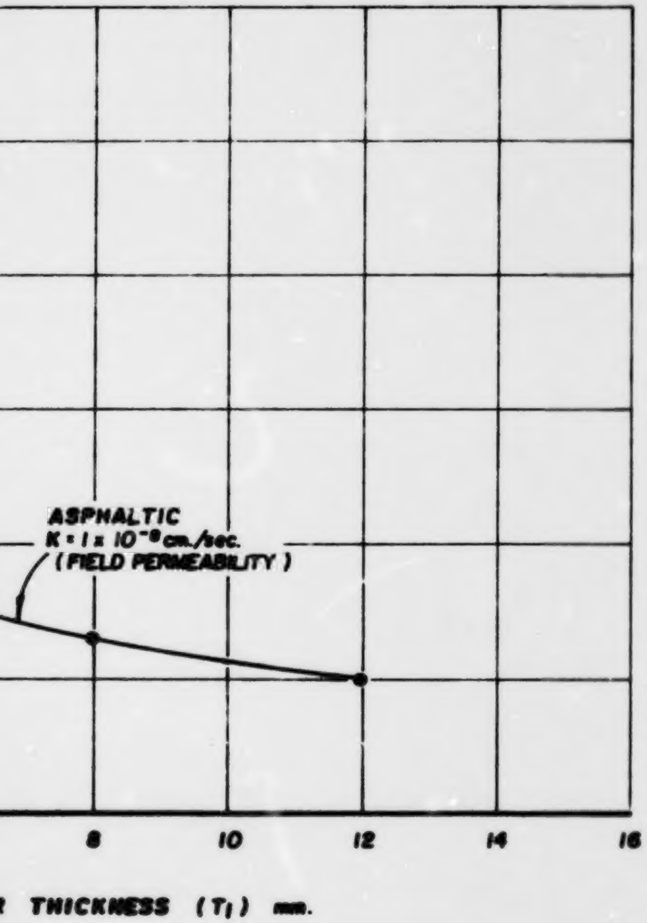
TAILINGS BASIN


RELEASE RATE (Q) L/sec.
60
50
40
30
20
10
0
0
20 mil
36 mil
60 mil
2
100 mil
120 mil
4
6
8
10
12
14
16
LINER THICKNESS (T_l) mm.
ASPHALTIC
$K = 1 \times 10^{-9}$ cm./sec.
(FIELD PERMEABILITY)
POLYMERIC
$K = 1 \times 10^{-10}$ cm./sec.
(FIELD PERMEABILITY)

POLYMERIC & ASPHALTIC LINERS

(TYPICAL OF SOUTHEASTERN ATHABASCA REGION)

FIGURE **13**



NOTES

$$Q = \frac{H_h}{\frac{H_t}{K_t} + \frac{T_l}{K_l}} \times A$$

H_h = PIEZOMETRIC HEAD

H_t = HEIGHT OF TAILINGS

T_l = THICKNESS OF LINER

K_t = PERMEABILITY OF TAILINGS

K_l = PERMEABILITY OF LINER

A = AREA OF POND (36 HECTARES)

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

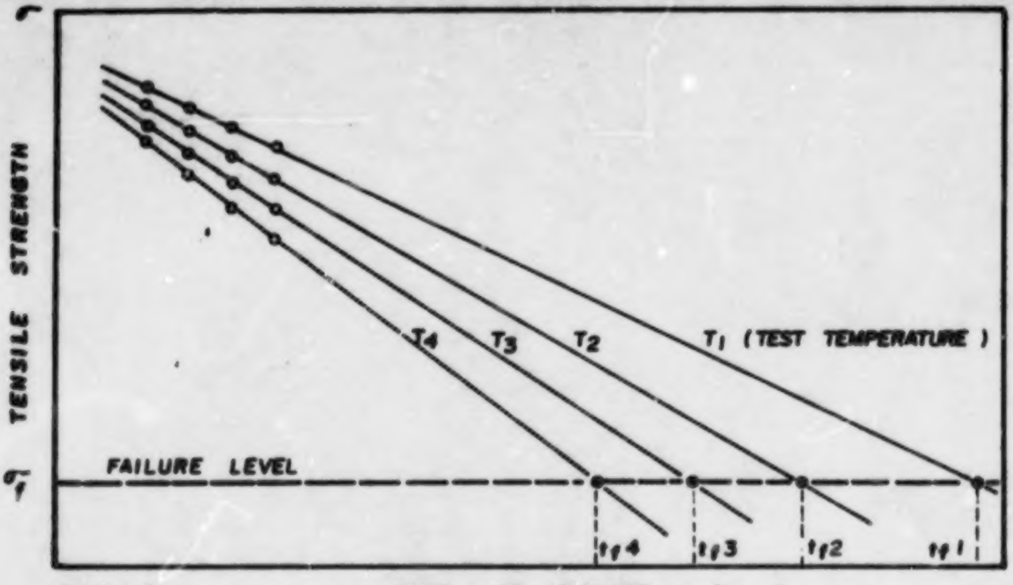
Date JULY 16, 1984.
Project 841-3016

Golder Associates

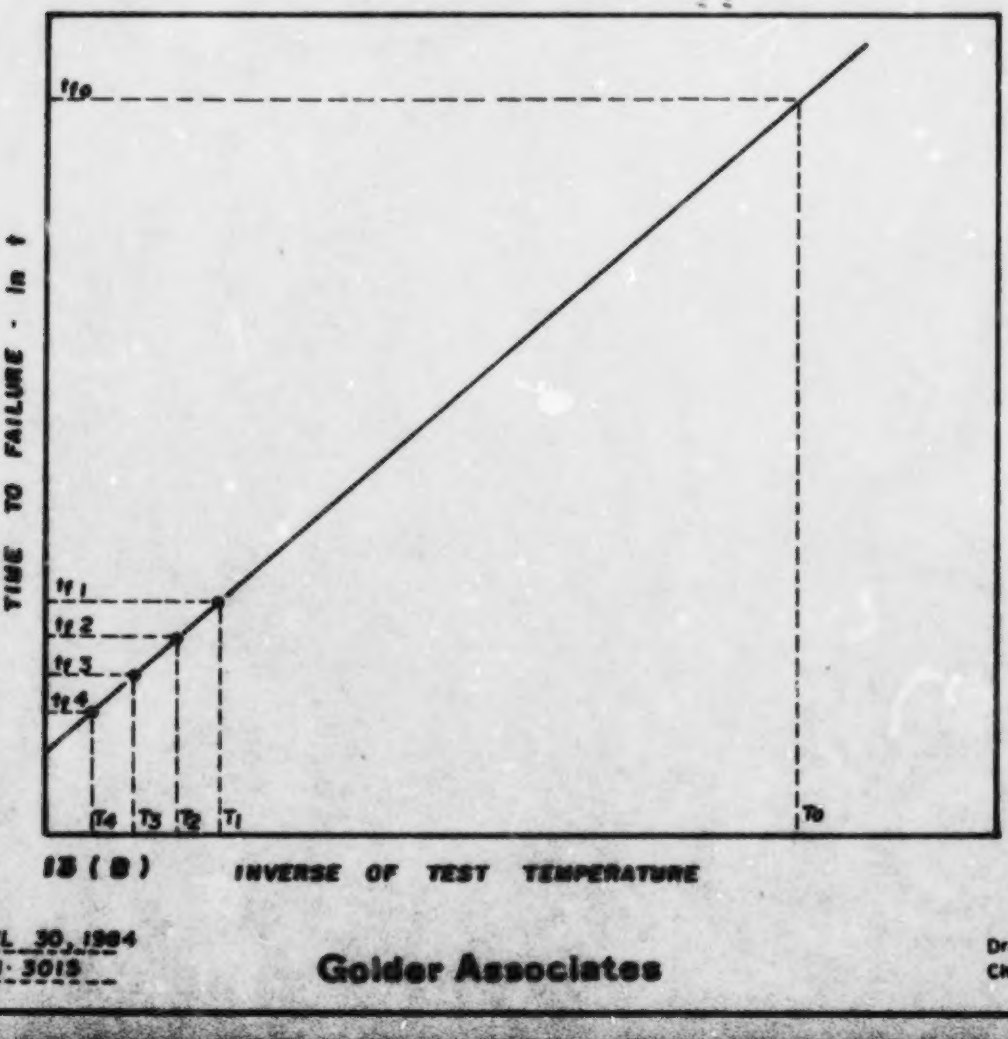
Drawn W.D.F.
Chkd

ACCELERATED TESTING

FIGURE



13 (A)



13 (B)

Date APRIL 30, 1984
Project 841-3015

Golder Associates

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ENERGY, MINES AND
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CANMET
NATIONAL URANIUM
TAILINGS PROGRAM

CONTRACT REPORT NO. OSQ83-00279

EVALUATION OF FLEXIBLE MEMBRANE LINERS AS LONG-TERM BARRIERS FOR URANIUM MILL TAILINGS. PHASE 1

VOLUME 2 OF 2
APPENDICES

MICROMEDIA

257 AP

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

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LIST OF APPENDICES

APPENDIX A Statement of Work

B Polymeric Flexible Membrane Liners Material Property Specifications and Special Test Methods and Test Procedures National Sanitation Foundation (NSF) Standard No. 54

C Representative List of Organizations in Liner Industry

D Liner Suppliers

E Liner Users

F Typical Warranties

APPENDIX A

STATEMENT OF WORK

STATEMENT OF WORK

TITLE

EVALUATION OF FLEXIBLE MEMBRANE LINERS AS LONG-TERM BARRIERS FOR URANIUM MILL TAILINGS - PHASE I

BACKGROUND

Many commercially available materials have been proposed or are in use as flexible liners to minimize the release of hazardous materials from waste ponds and deposits and in the containment of valuable liquids. Early applications of flexible liners often resulted from a need for short-term measures or a situation where the use of clays or clay-modified soils was impractical.

Flexible liners have seen limited use in the control of contaminant migration from uranium tailings. However, the use of such materials could increase if it is shown that migration rates of contaminants from uranium tailings deposits are unacceptable, if there is a significant cost advantage over natural materials and if the material is predicted to exhibit adequate stability in the long-term.

INFORMATION BASE AND RECOMMENDATIONS FOR TEST PROGRAM - PHASE I

The initial phase of the investigation will focus on the types of materials available, their manufacture, methods of placement and an assessment of performance. The contractor will assume that the materials will be protected from ultraviolet radiation by a soil, glacial till or saturated tailings cover. The contractor will concentrate his investigation on the two main uranium producing areas of Canada, but will address the use of these materials in other potential uranium-producing areas of Canada including areas of continuous permafrost. The flexible barriers will be considered for two applications:

(a) dam membrane
(b) complete tailings basin liner

The contractor will recognize that, for certain geographic areas, a bottom liner would be unnecessary because of impermeable strata located below the tailings deposit. Best practical engineering practice for site preparation and installation will be considered. For this investigation the time of consideration will be up to one thousand years (1000) after installation.

The contractor will undertake the following work:

(1) Describe the properties of up to 8 commercially available materials that can be used as flexible liners for uranium tailings. An example of such a material is chlorosulphonated polyethylene (Hypalon).

(2) Describe the manufacture of resin and sheet (if applicable) and the quality control measures necessary to ensure an acceptable product delivered to the field.

(3) Describe site preparation and installation procedures required to obtain a continuous liner. Include a description of techniques used to cement or weld joints (if applicable) and methods of field testing for acceptable joints.

(4) From available information, determine the estimated release rates of contaminants through the barrier as a function of time. For this study, the contractor will assume that the tailings pond is water-saturated and the tailings mass results from the production of 1.9 million Kg (5 million lb $U_3 O_8$) per year over 20 years, from a low grade mineralogy (brannerite-pyrite-quartz) deposit and a high grade complex mineralogy (U-Ni-As-Mo-Co-clay-silica) deposit. The extraction process is sulphuric acid leaching, solvent extraction solution purification and ammonia solvent stripping.

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(5) Determine, from available information, the expected failure mechanisms and rate of degradation of the liner in the expected field conditions. Include a description of expected failure mechanisms of factory and field joints (if applicable).

(6) Estimate the installation costs of each liner including site preparation for installation at two Canadian locations, in the southeastern Athabaska basin region of Saskatchewan and Elliot Lake - Blind River area of Ontario.

(7) Prepare a technical proposal and cost estimate for the Phase II test program. A preliminary description of Phase II is included below.

PHASE II (INFORMATION ONLY)

TEST PROGRAM FOR THE LONG-TERM STABILITY OF FLEXIBLE LINERS AND ANALYSES:

(Brief description only)

Since available information on the use of flexible liners as barriers in the control of contaminants from Canadian uranium tailings is limited, a laboratory test program is required to determine failure mechanisms, degradation rates and contaminant release rates through selected liners. The selection of liner materials will be done in consultation with the Scientific Authority.

PLEASE NOTE THAT PHASE II IS NOT PART OF THE REQUIREMENT FOR THIS CONTRACT

APPENDIX B

POLYMERIC FLEXIBLE MEMBRANE LINERS MATERIAL PROPERTY SPECIFICATIONS AND SPECIAL TEST METHODS AND TEST PROCEDURES

NATIONAL SANITATION FOUNDATION (NSF) STANDARD NO. 54

TABLE 2A. MATERIAL PROPERTIES

CHLORINATED POLYETHYLENE (CPE)

Property	Unsupported (U) Test Method	20	30
Gauge (nominal)	—	20	30
Thickness, mils minimum	ASTM D1593 Para. 8.1.3	19	28.5
Specific Gravity (minimum)	ASTM D792 Method A	1.20	1.20
Minimum Tensile Properties (each direction)	ASTM D882		
1. Breaking Factor (pounds/inch width)	Method A or B	34	43
2. Elongation at Break (percent)	Method A or B	250	300
3. Modulus (force) at 100% elongation (pounds/inch width)	Method A or B	8	12
Tear Resistance (pounds, minimum)	ASTM D1004 Die C	3.5	4.5
Low Temperature, °F	ASTM D1790	-20	-20
Dimensional Stability (percent change maximum)	ASTM D1204 212°, 15 min.	18	18
Water Extraction (percent loss maximum)	ASTM D3083 (as modified in Appendix A)	-0.35	-0.35
Volatile Loss (percent loss maximum)	ASTM D1203 Method A	0.7	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
1. Breaking Factor		5	5
2. Elongation at Break		20	20
3. Modulus at 100% Elongation		20	20
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A	75	100
	Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	27	34
Peel Adhesion (lbs/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in	FTB[2] or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
Peel Adhesion		-20	-20
Bonded Seam Strength		-20	-20

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[1] Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2] FTB - Film Tear Bond

[3] Film Tearing Bond is acceptable.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 1A. MATERIAL PROPERTIES
POLYVINYL CHLORIDE (PVC)

perty	Test Method	Unsupported (U) 10	20	30	45
uge (Nominal)	—	10	20	30	45
ickness, mils minimum	ASTM D1593 Para 8.1.3	9.3	19	28.5	42.75
ecific Gravity inimum)	ASTM D792 Method A	1.20	1.20	1.20	1.20
nimum Tensile Properties ach direction)	ASTM D882				
Breaking Factor (pounds/inch width)	Method A or B (1 inch wide)	23	46	69	104
Elongation at Break (percent)	Method A or B	250	300	300	300
Modulus (force) at 100% Elongation (pounds/inch width)	Method A or B	9	18	27	40
ar Resistance (pounds, nimum)	ASTM D1004 Die C	3	6	8	11
w Temperature, °F	ASTM D1790	-10	-15	-20	-20
nensional Stability ach direction, percent ange maximum)	ASTM D1204 212°F, 15 min.	5	5	5	5
ater Extraction rcent loss maximum)	ASTM D3083 (as modified in Appendix A)	-0.35	-0.35	-0.35	-0.35
latile Loss rcent loss maximum)	ASTM D1203 Method A	1.5	0.9	0.7	0.5
sistance to Soil Burial rcent change maximum original value)	ASTM D3083 (as modified in Appendix A)				
Breaking Factor		5	5	5	5
Elongation at Break		20	20	20	20
Modulus at 100% Elongation		20	20	20	20
drostatic Resistance ounds/sq. in. minimum)	ASTM D751 Method A	37	60	82	100
		Factory Seam Requirements[1]			
nded Seam Strength ctory seam, breaking ctor, ppi width)	ASTM D3083 (as modified in Appendix A)	18.4	36.8	55.2	83.2
l Adhesion undsin. minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 10 lb/in	FTB[2] or 10 lb/in	FTB[2] or 10 lb/in	FTB[2] or 10 lb/in
sistance to Soil Burial rcent change maximum original value)	ASTM D3083 (as modified in Appendix A)				
eel Adhesion		-20	-20	-20	-20
onded Seam Strength		-20	-20	-20	-20

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ctory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

B - Film Tearing Bond.

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TABLE 2B. MATERIAL PROPERTIES

CHLORINATED POLYETHYLENE (CPE)

Property	Test Method	Supported (S)		
		2-30	3-36	3-45
Gauge (nominal)	—	27	36	45
Thickness, mils minimum	ASTM D751			
1. Overall		32	34	41
2. Over Scrim	Optical Method (see Appendix A)	11	11	11
Breaking Strength (pounds, minimum)	ASTM D751	120	200	200
Tear Strength (pounds, minimum)	ASTM D751 (as modified in Appendix A)			
1. Initial		25	35	35
2. After Aging		20	25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel 4 hrs. Pass	-40	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 1 hr.	2	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A 30 mil sheet	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 30 mil sheet (as modified in Appendix A)			
a. Unsupported Sheet				
1. Breaking Strength		5	5	5
2. Elongation at Break		20	20	20
3. Modulus at 100% Elongation		20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Proc. 1	160	250	250
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 machine method Type A	10	7	7
		Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking strength, lbs min.)	ASTM D751 (as modified in Appendix A)	96	160	160
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lbs./in.	Ply sep in plane of scrim or 10 lbs./in.	Ply sep in plane of scrim or 10 lbs./in.
Resistance to Soil Burial (percent change maximum in original value	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

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[1] Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 3. MATERIAL PROPERTIES

BUTYL RUBBER (IIR)

Property	Test Method	Unsupported (U)		
		30	45	60
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D792	1.20±.05	1.20±.05	1.20±.05
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		36.0	54.0	72.0
2. Elongation at Break (percent)		300	300	300
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-40	-40	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	2	2	2
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 100 hours, 50 pphm 104°F, 20% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 7 days at 240°F			
1. Elongation (percent, minimum)		210	210	210
2. Breaking Factor (pounds/inch width, minimum)		25.2	37.8	50.4
Factory Seam Requirements[1]				
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	28.8	43.2	57.6
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load				
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

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[1] Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2] FTB - Film Tearing Bond

his table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. efore selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these aterials may not be appropriate for every application. Specific information should be obtained from the manufacturers garding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 6. MATERIAL PROPERTIES

ETHYLENE-PROPYLENE DIENE TERPOLYMER (EPDM)

Property	Test Method	Unsupported (U)		
		30	45	60
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D792	1.18±.03	1.18±.03	1.18±.03
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		42.0	63.0	84.0
2. Elongation at Break (percent)		300	300	300
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-55	-55	-55
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	2	2	2
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 7 days, 100 pphm 104°F, 50% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 7 days at 240°F			
1. Elongation (percent, minimum)		210	210	210
2. Breaking Factor (pounds/inch width, minimum)		36.0	54.0	72.0
Factory Seam Requirements[1]				
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	33.6	50.4	67.2
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load	See Appendix A			
Room Temperature 73°F 50% Bonded Seam Load		Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

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[1] Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2] FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 4. MATERIAL PROPERTIES

POLYCHLOROPRENE (CR)

		Unsupported (U)		
Property	**Test Method**	**30**	**45**	**60**
Gauge (nominal)	—	30	45	60
Thickness, mils minimum	ASTM D412	27	40.5	54
Specific Gravity	ASTM D297	1.48±.05	1.48±.05	1.48±.05
Minimum Tensile Properties (each direction)	ASTM D412			
1. Breaking Factor (pounds/inch width)		45.0	67.5	90.0
2. Elongation at Break (percent)		250	250	250
Tear Resistance (pounds, minimum)	ASTM D624 Die C	4	6	8
Low Temperature, °F	ASTM D746 Procedure B	-30	-30	-30
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 7 days	2	2	2
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
1. Breaking Factor		10	10	10
2. Elongation at Break		20	20	20
Water Absorption (percent change, maximum)	ASTM D471 158°F, 168 hours	12	12	12
Durometer A Hardness (points)	ASTM D2240 5 second reading	60±10	60±10	60±10
Ozone Resistance	ASTM D1149 100 hours, 100 pphm 104°F, 20% extension	No Cracks 7X	No Cracks 7X	No Cracks 7X
Heat Aging	ASTM D573 70 hours at 212°F			
1. Elongation (percent, minimum)		150	150	150
2. Breaking Factor (pounds/inch width, minimum)		38.2	57.4	76.5
		Factory Seam Requirements[1]		
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	28.8	43.2	57.6
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2] or 6 lb/in	FTB[2] or 8 lb/in	FTB[2] or 10 lb/in
Dead Load				
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass	Pass
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)			
Peel Adhesion		-20	-20	-20
Bonded Seam Strength		-20	-20	-20

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[1] Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2] FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 5. MATERIAL PROPERTIES

HIGH DENSITY POLYETHYLENE (HDPE)

Property	Test Method	Unsupported (U)	
		80	**100**
Gauge (nominal)	—	80	100
Thickness, mils minimum	ASTM D1593 Para. 8.1.3	72	90
Specific Gravity (minimum)	ASTM D792 Method A	0.930	0.930
Minimum Tensile Properties (each direction)	ASTM D638		
1. Tensile Strength Yield (lb/in width)		120	150
2. Tensile Strength at Break (lb/in width)		120	150
3. Elongation at Yield (percent)		10	10
4. Elongation at Break (percent)		500	500
5. Modulus of Elasticity (lb/sq in)		80,000	80,000
Tear Resistance (lb, minimum)	ASTM D1004 Die C	40	50
Low Temperature, °F	ASTM D746 Procedure B	-40	-40
Dimensional Stability (each direction, percent change maximum)	ASTM D1204 212°F, 15 min.	±3	±3
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)		
1. Tensile Strength Yield		10	10
2. Tensile Strength at Break		10	10
3. Elongation at Yield		10	10
4. Elongation at Break		10	10
5. Modulus of Elasticity		10	10
Environmental Stress Crack (minimum, hours)	ASTM D1693 (as modified in Appendix A)	500	500
Factory and Field Seam Requirements[1]			
Bonded Seam Strength (factory seam, breaking factor, ppi width)	ASTM D3083 (as modified in Appendix A)	108	135
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	FTB[2]	FTB[2]
Dead Load			
Room Temperature 73°F 50% Bonded Seam Load	See Appendix A	Pass	Pass
Elevated Temperature 158°F 25% Bonded Seam Load	See Appendix A	Pass	Pass
Resistance to Soil Burial	ASTM D3083 (as modified in Appendix A)		
Peel Adhesion		FTB[2]	FTB[2]
Bonded Seam Strength (percent change maximum in original value)		-20	-20

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[1] Factory bonded seam strength is the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

[2] FTB - Film Tear Bond

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 10A. MATERIAL PROPERTIES
CHLOROSULFONATED POLYETHYLENE (CSPE)

Property	Test Method	Supported (S)					
		Type 1-30	Type 1-45	Type 2-36	Type 2-45	Type 3-36	Type 3-45
Gauge (nominal)	—	30	45	36	45	36	45
Plies, Reinforcing	—	1	2	1	1	1	1
Thickness, mils minimum	ASTM D751						
1. Overall		27	41	32	41	34	41
2. Over Scrim	Optical Method (Reference Appendix A)	11	11	11	11	11	11
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	60[1]	90[1]	120	125	200	200
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)						
1. Initial		10	18	25	30	60	70
2. After Aging		5	5	20	25	25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel, 4 hrs., Pass	-40	-40	-40	-40	-40	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	7.5	5	2	3	2	2
Volatile Loss (percent loss maximum)	ASTM D1203 Method A, 30 mil sheet	0.5	0.5	0.5	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)						
a. Unsupported sheet							
1. Breaking Strength		5	5	5	5	5	5
2. Elongation at Break		20	20	20	20	20	20
3. Modulus at 100% Elongation		20	20	20	20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80	140	160	180	250	250
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	10	10	10	10	7	7
Factory Seam Requirements[2]							
Bonded Seam Strength (factory seam, breaking factor, lb, width)	ASTM D751 (as modified in Appendix A)	80	96	96	100	160	180
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)						
Peel Adhesion		20	20	20	20	20	20
Bonded Seam Strength		-25	-25	-25	-25	-25	-25

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[1] Type 1 gauge liner has two values. Coating is stronger than fabric and gives a breaking strength value of 100 pounds for nominal 30 mil and 120 pounds for nominal 45 mils with 150% minimum elongation at break for both.

[2] Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

TABLE 10B. MATERIAL PROPERTIES CHLOROSULFONATED POLYETHYLENE (CSPE-LW) LOW WATER ABSORPTION

		Supported (S)						
Property	**Test Method**	**Type 1-30**	**Type 2-36**	**Type 2-45**	**Type 2-60**	**Type 3-36**	**Type 3-45**	**Type 3-60**
Gauge (nominal)	—	30	36	45	60	36	45	60
Plies, Reinforcing	—	1	1	1	2	1	1	1
Thickness, mils minimum	ASTM D751							
1. Overall		27	32	41	56	34	41	56
2. Over Scrim	Optical Method (Reference Appendix A)	11	11	11	11	11	11	11
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	60[1]	120	125	300	200	250	300
Tear Strength (pounds, minimum)	ASTM D751 (As modified in Appendix A)							
1. Initial		10	25	30	100	60	70	60
2. After Aging		5	20	25	40	25	25	25
Low Temperature, °F	ASTM D2136 ⅛ in. mandrel, 4 hrs., Pass	-40	-40	-40	-40	-40	-40	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	7.5	2	3	4	2	2	4
Volatile Loss (percent loss maximum)	ASTM D1203 Method A, 30 mil sheet	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Resistance to Soil Burial (percent change maximum in original values)	ASTM D3083 30 mil sheet (as modified in Appendix A)							
a. Unsupported sheet								
1. Breaking Strength		5	5	5	5	5	5	5
2. Elongation at Break		20	20	20	20	20	20	20
3. Modulus at 100% Elongation		20	20	20	20	20	20	20
b. Membrane Fabric Breaking Strength	ASTM D751 Method A	25	25	25	25	25	25	25
Hydrostatic Resistance (pounds/sq. in. minimum)	ASTM D751 Method A, Procedure 1	80	180	180	300	250	250	300
Ply Adhesion (each direction pounds/in. width minimum)	ASTM D413 Machine Method Type A	10	10	10	10	7	7	7
Water Absorption (percent weight gain maximum 30 mil unsupported sheet)	ASTM D471							
	14 days @ 70°F	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	30 days @ 70°F	2.0	2.0	2.0	2.0	2.0	2.0	2.0
	14 days @ 158°F	30.0	30.0	30.0	30.0	30.0	30.0	30.0
	30 days @ 158°F	30.0	30.0	30.0	30.0	30.0	30.0	30.0
				Factory Seam Requirements[2]				
Bonded Seam Strength factory seam, breaking factor, lb, width)	ASTM D751 (as modified in Appendix A)	80	96	100	180	200	250	275
Peel Adhesion (lb/in minimum)	ASTM D413 (as modified in Appendix A)	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in	Ply sep in plane of scrim or 10 lb/in
Resistance to Soil Burial (percent change maximum in original value)	ASTM D3083 (as modified in Appendix A)							
Peel Adhesion		-20	-20	-20	-20	-20	-20	-20
Bonded Seam Strength		-25	-25	-25	-25	-25	-25	-25

---

[1] Type 1 liner has two values. Coating is stronger than fabric and gives breaking strength values of 100 pounds for nominal 30 mil with 150% minimum elongation at break.

[2] Factory seam requirements are the responsibility of the fabricator. Factory seams are further discussed in Item 4.2.

This table provides a reliable and dependable means for industry to furnish such materials of known and consistent quality. Before selection of any material for an FML, however, the user should consult with appropriate manufacturers, because these materials may not be appropriate for every application. Specific information should be obtained from the manufacturers regarding installation requirements, exposure conditions, performance expectations, and experience factor.

APPENDIX A

Special Test Methods and Revision of Standard Test Procedures

TABLE OF CONTENTS

Part 1 Water Extraction
Part 2 Bonded Seam Strength
Part 3 Soil Burial
Part 4 Peel Adhesion
Part 5 Tear Strength
Part 6 Thickness Over Scrim
Part 7 Chemical/Taste and Odor
Part 8 Ply Adhesion
Part 9 Weather Resistance
Part 10 Dead Load Seam Strength
Part 11 Dead Load Seam Strength at Elevated Temperature
Part 12 Environmental Stress Crack Resistance

Part 1

Water Extraction

ASTM D3083 Paragraph 9.6 modified to be::

A. Apparatus

1. Balance: An analytical balance
2. Containers: Pint jars or cans with a diameter of at least 2.5 inches (6.5 cm) (one container for each specimen)
3. Oven
4. Desiccator

B. Materials

Water: Freshly prepared distilled or deionized water.

C. Test Specimens

The test specimens for plastic films shall be in the form of squares 50 ± 0.25 mm (2 inches) on each side. At least three specimens of each sample shall be tested with each chemical reagent.

D. Conditioning

Condition the test specimens at 73.4 ± 3.6°F (23 ± 2°C) in a desiccator for not less than one hour prior to test.

E. Procedure

1. Maintain the water at the test temperature for at least 4 hours before the specimens are immersed.
2. After being weighed, immerse the specimens in the water, one specimen to each container. Each jar shall contain 400 ml. Suspend the specimen freely in a vertical position, but fully covered by the liquid. To prevent each specimen from floating or curling, it may be necessary to attach small weights, such as paper clips.
3. Cover the jars containing the specimens and keep at 122 ± 3.6°F for 24 hours.
4. Remove the specimens from the liquids and gently wipe with a soft cloth or absorbent tissue. Dry the specimens for 24 hours in a desiccator at 73.4 ± 3.6°.
5. It is realized that there may be an increase in weight of the test specimen due to water absorption. It is necessary to determine if a correction factor is needed, and the value of the correction factor. Prepare and condition control specimens in the same manner as for the standard test, but expose them for only 5 mintues and dry as specified in Section E.5. If the control sample has a weight gain the calculated percent weight gain of the control is the correction factor that is used to adjust the value obtained in the test.

F. Calculations

1. The percentage loss in weight from extraction, expressed as percentage weight loss compared to the original specimen weight, shall be calculated as follows:

   Weight loss, percent = $(W_1 - W_2)/W_1 \times 100$ where:

   W_1 = weight of specimen after the conditioning period and,
   W_2 = weight of specimen at the end of the test.

2. The values obtained for the three specimens for percentage weight loss shall be averaged and this value reported as the percentage weight loss of the sample being tested.

Part 2

Bonded Seam Strength

Unsupported Materials:

ASTM D3083, Paragraph 9.3 is modified to permit either Method A or Method B of ASTM D882.

A specimen 1 inch wide is used with a grip separation of 4 inches plus the width of the seam. The seam is to be centered between the clamps. The rate of grip separation will be 20 inches per minute or as specified in the materials properties tables.

Supported Materials:

ASTM D751 Section A Grab Method shall be modified as follows:

Section 10.1 - Last sentence shall be changed to read: "the distance between the clamps at the start of the test shall be 6 inches plus the seam width. Seam is to be centered between the clamps."

Sections 11 and 12 of ASTM D751 shall be revised to be:

11. Test Specimens

Specimens 100 mm (3.93 in.) in width and not less than 200 mm (7.87 in.) plus the seam width in length shall be cut from the membrane for test. One set of five specimens will be required.

12. Procedure

12.1 Test Conditions

Heat-sealed test specimens shall be conditioned for a minimum of 24 hours at 23°C (73.4°F).

Adhesive seamed specimens shall be conditioned for a minimum of 12 days at 23° (73.4°F). After this period, if it appears that the adhesive seam is not dry and suitable for testing, the seams may be placed in a circulating oven at 70°C (158°F) for 3 hours and allowed to rest at 23° (73.4°F) for 48 hours before retesting.

12.2 Procedure

Place the specimen symmetrically in the clamps of the machine (see Figure 1) with the longer dimension parallel to and the shorter dimension at right angles to the direction of application of the force.

The rate of loading shall be at the rate of 12 ± 0.5 in./min. (5 ± 0.1 mm/s).

Record the maximum stress applied to the specimen at yield or breakage.

SEAM STRENGTH

MODIFIED ASTM D 751 GRAB METHOD

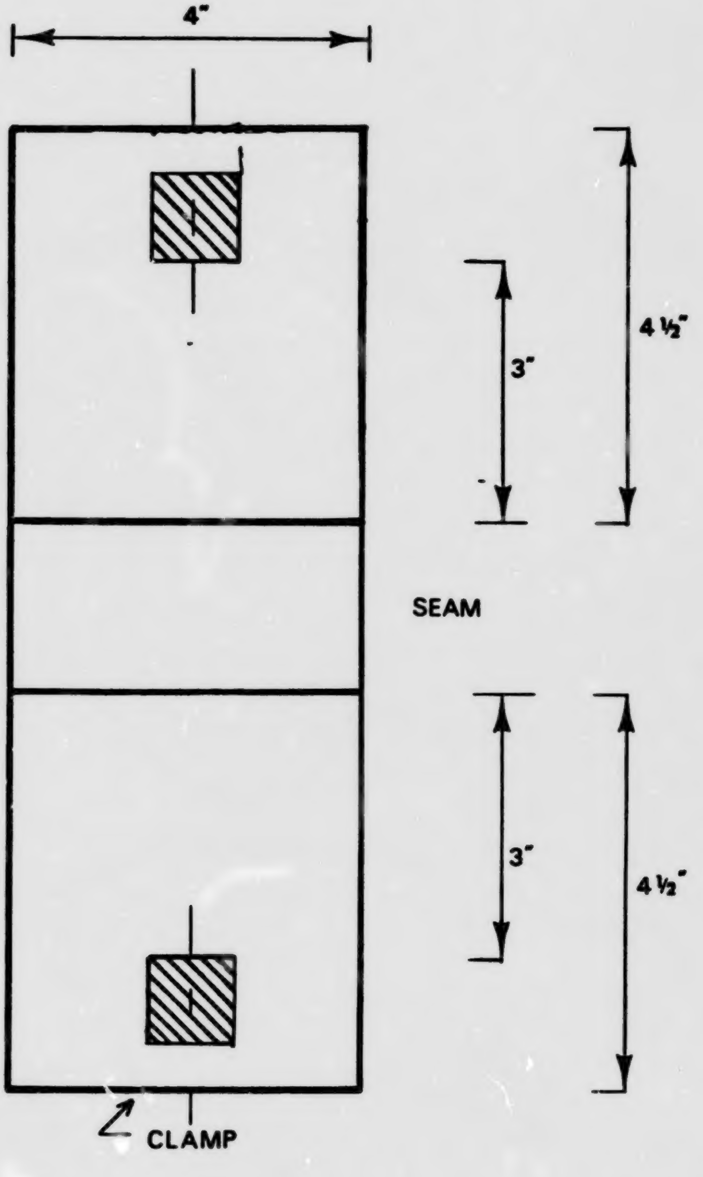

4"
3"
4 ½"
SEAM
3"
4 ½"
CLAMP

FIG. 1

Part 3

Soil Burial

ASTM D3083, Paragraph 9.5 is modified to be:

The test value of the after-exposure specimen shall be based upon the precut sample dimension.

The test method used to determine before and after exposure tensile properties shall be the test method specified in the materials properties tables for the tensile properties of the material.

Specimens are to be prepared and buried vertically to a depth of 5 inches and exposed as specifed in ASTM D3083, Paragraph 9.5.

Tests for Unsupported Materials

Testing shall be conducted on specimens prepared from the actual flexible membrane liner.

Tests for Supported Materials:

Fabric: Testing shall be conducted on specimens of the fabric used in the supported sheet. Six specimens (4 inches wide by 6 inches long) shall be prepared, three in the warp direction and three in the fill direction. When testing the fabric by itself (no polymeric membrane coating) before and after soil burial, it will be necessary to make sure slippage does not occur. This can be done by using tape, sandpaper or cloth material, special jaws, etc., It is also important to note that consecutive fibers that are grabbed in one jaw correspond to exactly the same fibers grabbed in the other jaw.

Sheet Material: Testing shall be conducted on 30 mil unsupported sheet prepared from the sheeting or coating compound used to produce the supported flexible membrane liner.

Tests for Factory Seams

Testing shall be conducted on specimens prepared from actual flexible membrane liner factory fabricated seams with sealed edges.

Part 4

Peel Adhesion

ASTM D413 shall be modified to be:

Strip specimen Type A, 180° peel, modified to be 1 inch sample width pulled at a rate of 2 inches/minute. Use bonding technique employed in seam joint construction.

Part 5

Tear Strength

ASTM D751 shall be modified to be:

Tear strength of supported materials shall be determined using Method B - Tongue Tear Method. The test specimen shall be 8 x 8 inches. For oven aging tear strength, initial values and values after aging in an oven at 212°F for 30 days shall be determined.

PART 6

OPTICAL METHOD FOR MEASURING THICKNESS
OF
MATERIAL OVER SCRIM
(SUPPORTING FABRIC)

A. Scope and Application

This is a method for measuring the thickness of a membrane over the reinforcing fabric.

B. Principle

The thickness of membrane material over reinforcing fabric can be observed with a standard reflectance microscope. Measurement is made with a calibrated eyepiece.

C. Accuracy

Measurements are accurate to ±0.5 mils when the thickness is about 20 mils.

D. Apparatus

1. Microscope, 60X with reticle
2. Light source

   If light source on the microscope is not adequate, a small tensor lamp can also be used.
3. Stage Micrometer (0.001 inch divisions)

E. Procedure

1. Calibration

   a. Place a standard reflectance stage micrometer in the plane of the sample.

   b. Turn on the microscope light source.

   c. Position the reticle eyepiece and the micrometer such that the scales are superimposed. Focus the reticle by turning the eyepiece. Focus the sample and reticle by turning the vertical adjustment knob.

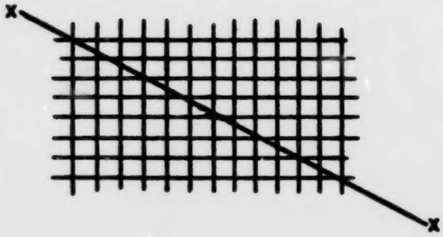
   d. Locate a point at which both scales line up. Count the number of micrometer divisions between that point and several reticle divisions away. Measure to the nearest 0.5 mil.

   The calibration may be optimized by increasing the number of divisions measured.

   e. Repeat the calibration three times and average the results.

2. Sample Analysis

   a. Carefully center a sharp, single edge razor or equivalent over the fiber intersections along the x - x line.



b. Make a clean bias cut *completely* through the liner.

c. Remove the razor cut section and mount in common putty with the cut surface facing upward.

d. Observe the cut surface with the eyepiece reticle. Measure the thickness of the liner on either side of the thread intersection by counting the number of reticle divisions (to the nearest one-half division).

e. Sample two or three areas of the liner and average the results.

F. Calculations

1. Calibration

A calibration example is given below:

In the above example, 4.5 micrometer divisions (MD) are equal to 4 reticle divisions (RD).

4 (RD) = 4.5 (MD)
1 (RD) = 4.5/4 (MD)
1 (RD) = 1.1 (MD)

One micrometer division is equal to one mil, therefore:

1 RD = 1.1 mils

This calculated value (1.1 mils in the example) is the calibration factor.

2. Sample

Multiply the number of reticle divisions by the calibration factor. Report results to the nearest 0.5 mil.

PART 7
Chemical/Taste and Odor
A - Review Procedures for Ingredients Intended for NSF Listed Potable Water Formulations

SECTION I. GENERAL

A. GENERAL: The ingredient review procedures detailed below include those for:

1. ACCEPTANCE of a new ingredient[1] and a generically similar ingredient[2]
2. QUALIFICATION of a new compound or material or change in formulation
3. MONITORING of a listed product

---

[1] New Ingredient - any chemical or substance not previously accepted for use in products intended for application in potable water liners.

[2] Generically Similar Ingredient - an ingredient that is not considered a "new ingredient" and while generically similar to an accepted ingredient, it may vary in composition due to manufacturing process, source of materials, potential trace contaminants, etc.

B. ACCEPTANCE STAGE - NEW INGREDIENTS: Samples shall be submitted of liner formulated to contain the ingredient of interest at twice the recommended maximum use level. Consult NSF if the physical characteristics are significantly modified at twice the recommended maximum use level.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.
2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the first exposure; and no greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.
3. If the basic constituent of the ingredient is not on the FDA list of sanctioned materials or the EPA List of Accepted Ingredients, 90-day animal feeding study[3] and Ames test data shall be conducted and the data submitted to NSF. The protocol for the 90-day animal feeding study shall include feeding levels at effect, no known effect, and an intermediate level.
4. If the ingredient is accepted in the U.S. Code of Federal Regulations, Title 21 Food and Drugs Regulations, the applicable section shall be referenced.
5. The ingredient supplier shall provide the chemical abstracts registry number.
6. The ingredient supplier shall submit the chemical description of the ingredient including molecular structure, and percent of components. A list of known contaminants shall be provided and the amounts in ppb. NSF shall be notified of ingredient(s) containing known carcinogens with appropriate references cited.
7. A complete literature review may be required to support application for acceptance.
8. The ingredient manufacturer shall certify that the ingredient is suitable for use in a potable water product.
9. If the extraction test and 90-day feeding study (if required) as well as the other information submitted by the ingredient supplier are acceptable, the ingredient shall be accepted for use in products listed under NSF Standard No. 54 for potable water applications.

C. ACCEPTANCE STAGE — GENERICALLY SIMILAR INGREDIENT: Samples shall be submitted of liner formulated to contain the ingredient of interest at twice the recommended maximum use level. Consult NSF if the physical characteristics are significantly modified at twice the recommended use level.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.
2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the first exposure; and no level greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.
3. If the ingredient is accepted in the U.S. Code of Federal Regulation, Title 21 - Food and Drugs, the applicable section shall be referenced.
4. The ingredient supplier shall provide the chemical abstracts registry number.
5. The ingredient supplier shall submit the chemical description of the ingredient including molecular structure and percent of components. A list of known contaminants shall be provided and the amounts in ppb. NSF shall be notified of ingredient(s) containing known carcinogens with appropriate references cited.
6. A complete literature review may be required to support application for acceptance.
7. The ingredient supplier shall certify that the ingredient is suitable for use in a potable water product.

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[3] It is suggested that the protocol for the feeding study be reviewed by toxicologists for their suggestions prior to the beginning of any actual animal feeding studies.

8. If the extraction test as well as the other information submitted by the ingredient supplier is acceptable, the ingredient shall be accepted for use in products listed under NSF Standard 54 for potable water applications.

D. QUALIFICATION STAGE: To qualify a new material, compound or product, or to change an ingredient in an accepted formula, the formulation and a sample shall be submitted for evaluation.

1. Samples shall be exposed by NSF using the standard (multiple) exposure procedure.
2. No level of a constituent of interest greater than 10 times the MCL (NSF Standard 54,Table 3.2-1) shall be measurable in water from the first exposure; and no level greater than the MCL (NSF Standard 54, Table 3.2-1) shall be measurable in water from the third exposure.

E. MONITORING STAGE (LISTED PRODUCTS): Samples of listed products shall be selected randomly by NSF personnel during unannounced visits to production facilities. Samples may be taken during production or from inventory.

1. Sample shall be extracted by NSF under standard (multiple) exposure procedures.
2. Levels measured shall not be greater than the established MCL specified for "monitoring."

ACCEPTANCE	**QUALIFICATION**	**MONITORING**
(New Ingredient or Generically Similar)	*(New Product or Change in Formulation)*	
Twice Recommended Maximum Use Level	Recommended Maximum	Use Level
Multiple Exposure	Multiple Exposure	Multiple Exposure
pH 5.0	pH 5.0	pH 5.0
MCL[4]: 1st extraction ≤10 X MCL[4] 3rd extraction ≤ MCL[4]	MCL[4]: 1st extraction ≤10 X MCL[4] 3rd extraction ≤ MCL[4]	3rd extraction ≤MCL[4]

B - Laboratory Procedures for Sample Preparation Extractant Water Exposure Taste and Odor

SECTION I. SAMPLES

A. REQUIREMENTS:

Liner: Use a "standard" ratio equivalent to 50 cm² surface area of liner sample to 1 liter of extractant water for all exposures.

Joining Materials: Use a "standard" ratio equivalent to 2.5 cm² surface area to 1 liter of extractant water.

---

[4] Maximum Contaminant Level, U. S. Environmental Protection Agency's National Interim Primary Drinking Water Regulations - 1978 and NSF limits of acceptance as shown in NSF Standard 54, Table 3.2-1.

B. SAMPLE PREPARATION:

Liners: Cut a portion of the liner into four individual circles 3¼ inches in diameter. Place the samples in a labeled stainless steel backet and wash in cold water utilizing a "detergent wash" and a "distilled water rinse" (EL detergent 101 and El detergent additive 601 are used for washing; Economics Laboratories, Inc., St. Paul, MN 55102). Finally, rinse the samples in an organic-free[1] water, and place in a laminar flow hood until they are dry and/or to be exposed.

Joining Materials: Coat one-fourth of the surface (on one side) of two standard laboratory glass slides (1 x 3 inch) with the adhesive, solvent, or bodied solvent. Allow the specimens to cure for 48 hours at ambient temperature. Wash the sample as for liners.

SECTION II. EXTRACTANT WATER

A. CHEMICAL CHARACTERISTICS: Prepare "standard" extractant water to contain 100 mg/l hardness (as $CaCO_3$) and 0.5 mg/l chlorine in organic-free water[1]. Adjust pH to 5.0 ± 0.2 with CO_2.

B. REAGENTS: Buffer Stock Solution: Dissolve 3.36 g sodium bicarbonate ($NaHCO_3$) in organic-free water.[1] Make up to one liter. Make fresh daily.

Hardness Stock Solution: Dissolve 4.44 g chloride (anhydrous $CaCl_2$) in organic-free water[1]. Make up to one liter. Make fresh daily.

Chlorine Stock Solution: Add 7.3 ml sodium hypochlorite (5 percent NaOCl) to 200 ml distilled water. Make fresh weekly. Keep in tightly stoppered bottle. Determine the strength of the chlorine stock solution by diluting 1 ml to 1 liter with standard extractant water, and immediately analyze for total available residual chlorine. Reference this determination as "A." Determine the volume of Cl_2 stock solution necessary to add to the exposure water with the formula:

$$Cl_2 \text{ stock solution (ml)} = \frac{0.5\,B}{A}$$

where:
A = ppm Cl_2 equivalent per ml of Cl_2 stock solution
B = liters of standard extractant water

C. WATER: Prepare "standard" extractant water by adding stock reagent solutions to organic-free water[1], as shown in Table A-I.

Table A-I

"Standard" Extractant Water

Organic-free Water[1] (liters)	Buffer Stock Solution (ml)	Hardness Stock Solution (ml)	Chlorine Stock Solution (ml)
1	25	25	0.5
6	150	150	3.0
12	300	300	6.0
15	375	375	7.5

Bubble with CO_2 until pH 5.0 ± 0.2 is attained.

---

[1] Organic-free water is defined as water free of interference when employed in the procedure described herein.

SECTION III. EXPOSURE

A. **VESSEL EXPOSURES, LINER:** Use 2 one quart "Mason" type jars to expose 50 cm^2 of liner sample in 1 liter of "standard" water. When cut as a lid liner, approximately 30 cm^2 of liner material will be exposed. Therefore, the volume of water used must be determined to maintain the required 50 cm^2/liter surface area to water volume ratio.

JOINING MATERIALS: Coat one-fourth of the surface (on one side) of two standard laboratory glass slides (1 x 3 inch) with the adhesive, solvent, or bodied solvent to obtain approximately 10 cm^2 of exposed surface. Allow the specimens to cure for 48 hours at ambient temperature. The specimens shall be immersed in 4 liters of extractant water to obtain a surface area to water volume ratio of 2.5 cm^2/l.

B. **EXPOSURE CONDITIONS, GENERAL:** All tests for acceptance, qualification and routine monitoring shall be conducted with the multiple exposure procedure.

1. 24±1 hour at 37±0.5°C
2. 24±1 hour at 37±0.5°C
3. 72±4 hours at 37±0.5°C

Controls: Place equivalent volume of formulated water in extraction vessel and expose as a control. Include one control for each combination of extraction vessel and/or exposure condition in the daily sample run.

Liners: Use A "Wide Mouth" one quart "Mason" type jar to expose each of the four specimens. Place a 11.6 cm length of 1¼ inch glass rod in each exposure jar (to displace the exposure water enough to fill the jar). Fill the jar with extractant water and seal without a head space utilizing the sample specimen as a cap liner. During the course of the exposure period, lay the exposure vessel upside down.

Joining Materials: Place one of the prepared slides on the bottom of each of two, two quart "Mason" type jars. Fill the jars with extractant water and seal without a head space utilizing an aluminum foil lined cap.

SECTION IV. RECOVERY OF WATER FOLLOWING EXPOSURE

A. **TRIHALOMETHANE SAMPLE:** Obtain an exposure water sample from one of the jars immediately after opening. Specifically, place 2.5 to 3 mg ACS Reagent Grade sodium sulfite in a 40 ml vial. Overflow it with the exposure water sample and seal without a head space utilizing a Teflon lined cap.

B. **CHEMICAL, TASTE AND ODOR SAMPLE:** Separate water from exposed samples immediately after exposure vessels are removed from the elevated temperature environment by pouring through filter paper (white, crepe, VWR Grade 6.5) into a ground glass stoppered bottle. Combine the waters from each of the four liner specimens or two joining materials samples into one bottle.

SECTION V. TASTE AND ODOR EVALUATION

ODOR TEST:

A. **GENERAL REQUIREMENTS:** Final extractant water exposed to liners shall have a threshold odor number less than 80. A paired sample technique in which the stronger odor in each pair is identified shall be used in determining threshold odor levels.

B. **TEST PROCEDURES:** The NSF odor procedure is a modification of the paired sample technique described in American Society for Testing and Materials (ASTM) Special Technical Publiation 434: *Manual on Sensory Testing Methods,* prepared by ASTM Committee E-18. The modified procedure permits the panel member to identify the member of the sample/control pair containing the strongest odor versus identification of the control bottle in the pair. Statistical basis for the paired sample technique is noted.

Odor Pairs: (Sample/Control)

Sample: Dilute the sample 1 to 80 by combining 2.5 ml of the final extractant with 197.5 ml of odor-free water in a BOD bottle.

Control: Dilute the control 1 to 80 by combining 2.5 ml of the final extractant with 197.5 ml of odor-free water in a BOD bottle.

Generate a second pair of the same by duplicating the above.

(Note: Odor-free water is prepared by passing distilled water through activated carbon.)

Numbers of Samples: No less than 4 and no more than 14 odor pairs shall be evaluated at any time.

Panel: Use panel of at least 10 members prescreened to eliminate persons who are unusually sensitive or insensitive to tastes and odors.

Preselect a random arrangement of the odor pairs for evaluation. For any given sample insure that the control is located once on the left and once on the right of the sample within its two odor pairs.

Hold BOD bottles containing samples and paired controls in a water bath at 22°C.

A minimum of 10 panel members shall examine each pair in turn to determine which member of the pair has the strongest odor.

C. RESULTS: Data from all panel members are summed and reported as to the number of times the sample was selected as the member of the pair which contained th stronger odor. Table A-II is then used to determine the confidence level (%) that the sample has the stronger odor. A sample fails the odor test when that confidence level reaches 99% or greater.

TABLE A-II

CONFIDENCE LEVELS[3]

No.[1]	No. of responses 20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
10	N.S.[2]														
11	N.S.	N.S.													
12	75.00	60.00	N.S.												
13	90.00	75.00	60.00	N.S.											
14	95.00	75.00	75.00	60.00	N.S.										
15	97.50	90.00	75.00	75.00	60.00	N.S.									
16	98.00	97.50	90.00	75.00	75.00	60.0	N.S.								
17	99.50	98.00	95.00	90.00	75.00	75.00	60.00	N.S.							
18	99.50	99.50	97.50	95.00	90.00	75.00	75.00	N.S.	N.S.						
19	99.95	99.50	99.50	97.50	95.00	90.00	75.00	75.00	60.00	N.S.					
20	99.95	99.95	99.50	99.00	99.00	95.00	90.00	75.00	60.00	60.00	N.S.				
21		99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	60.00	60.00	N.S.			
22		99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	60.00	60.00	N.S.		
23			99.95	99.95	99.50	99.50	97.50	97.50	95.00	75.00	75.00	60.00	60.00	N.S.	
24			99.95	99.95	99.95	99.50	99.00	97.50	97.50	90.00	75.00	75.00	60.00	60.00	N.S.
25				99.95	99.95	99.95	99.95	99.00	97.50	95.00	90.00	90.00	75.00	60.00	60.00
26				99.95	99.95	99.95	99.95	99.50	99.00	97.50	95.00	90.00	75.00	75.00	60.00
27					99.95	99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00	75.00	75.00
28					99.95	99.95	99.95	99.95	99.95	99.50	99.00	97.50	95.00	90.00	75.00
29						99.95	99.95	99.95	99.95	99.50	99.50	99.00	97.50	95.00	90.00
30						99.95	99.95	99.95	99.95	99.50	99.50	99.50	97.50	97.50	95.00
31							99.95	99.95	99.95	99.95	99.50	99.50	99.50	97.50	97.50
32							99.95	99.95	99.95	99.95	99.95	99.50	99.50	99.00	97.50
33								99.95	99.95	99.95	99.95	99.95	99.50	99.50	99.00
34								99.95	99.95	99.95	99.95	99.95	99.95	99.50	99.50
35									99.95	99.95	99.95	99.95	99.95	99.50	99.50
36									99.95	99.95	99.95	99.95	99.95	99.95	99.50

[1] Number of times sample identified as strongest odor in sample/control pair

[2] N.S. = No significant difference.

The confidence levels given in Table A-II are described as 1-p, where p is the probability of getting at least the specified number of correct identifications of the control, given that the control is identical to the sample (e.g., 99 percent confidence level means that 1 percent of the time, at least the specified number is expected when there is no difference in the odor of the sample and control).

Confidence levels in Table A-II are obtained from the percentiles of the "t" distribution. This distribution is parameterized by the sampling degrees of freedom. The degree of freedom is 19 for the test procedure using ten panel members and two pairs containing the sample and control.

The t-value is computed by the formula:

$$t = \frac{F - 0.5}{\sqrt{\frac{.5 \times .5}{19}}} = \sqrt{19}\ (2F - 1)$$

where F = the fraction of correct choices, t can be evaluated for different numbers of correct identifications of the control:

Number Correct	t-value	Confidence Level (%)
14	1.74	90.0
15	2.18	97.5
16	2.62	98.0
17	3.05	99.50
18	3.49	99.50
19	3.92	99.95

These are the entries for No. responses equal to 20 in Table A-II; the other entries in Table A-II were obtained in a like manner.

TASTE TEST:

D. TEST PROCEDURES: Place 200 ml final extractant water (i.e., water from final exposure period) for each sample in separate BOD bottles. Place 200 ml control water in BOD bottle.

Maintain all bottles - extractant water and control - at room temperature.

Arrange samples and control in random order for evaluation by panel.

Do not indicate to the panel which bottle contains control water.

A panel member shall pour taste samples into 25 ml beaker and record taste as "sweet," "sour," "bittler" or "salty."

Panel member shall rinse mouth with odor-free water before proceeding to the next taste sample.

E. RESULTS: If panel consistently reports the taste of a particular sample to be more disagreeable than taste of the control, sample fails the taste test.

SECTION VI. CHEMICAL METHODS

A. HEAVY METALS

1. GENERAL: The determination of heavy metals in extractant water is accomplished, using atomic absorption analysis. This technique is based on the quantum mechanical principle that atoms absorb light at energy levels corresponding to characteristic orbital energies of the atom. By measuring the attenuation of a monochromatic light beam passing through the sample atoms, the concentration of metal in the sample can be determined using Beer's Law.

NSF employs an external standard technique for calibration and sample determination. Three standard solutions are made in concentrations corresponding to the region in which the samples are expected to lie. Standards are run concurrently with samples to insure quality control and to indicate any significant deviations in instrumental response. The concentrations of the samples are then obtained from graphs of absorbance versus concentration for the standards.

A study of testing results for several routine analyses was made to determine reproducibility and levels of detection obtained on average working days in the NSF laboratories. This study was done without the prior knowledge of laboratory personnel.

Detection limits were determined as twice the noise level of the recorder output for an analysis. Reproducibility was determined to be the standard deviation of the absorbance values obtained for a specific concentration of a standard. Arithmetic mean values of the standard were then plotted against concentration, and a least squares line drawn. Detection limits and reproducibility values were then determined from this graph. This procedure was followed for each metal. The results are shown in Table A-III.

Updating analytical procedures is a continuous process at NSF.

All standards and samples are made in the matrix of NSF formulated extractant water[2].

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[1] Reference ASTM Special Technical Publication 434: *Manual on Sensory Testing Methods*, sponsored by ASTM Committee E-18 on Sensory Evaluation of Materials and Products.

[2] NSF Standard No. 14, Appendix A, Section 2.

TABLE A-III

DETECTION LIMITS AND REPRODUCIBILITY OF METALS ANALYSES

Metal	MCL[1] (mg/l)	Reproducibility at MCL (mg/l)	DL[2] (mg/l)	Reproducibility at lowest standard (mg/l)
Antimony	0.05	±0.0007	0.007	±0.0005
Arsenic	0.05	±0.0007	0.004	±0.0008
Barium	1.0	±0.05	0.008	±0.004
Cadmium	0.01	±0.0002	0.0005	±0.0001
Chromium	0.05	±0.002	0.005	±0.002
Lead	0.05	±0.0009	0.002	±0.0007
Mercury	0.002	±0.0004	0.0003	±0.0004
Selenium	0.01	±0.001	0.003	±0.0005
Tin	0.05	±0.002	0.005	±0.0009

[1] maximum contaminant level (MCL)

[2] detection limit (DL)

2. EQUIPMENT:

Perkin-Elmer Model No. 560 atomic absorption spectrophotometer

E.D.L. Power Supply, P.E. No. 040-0354

Perkin-Elmer Graphite Furnace, H.G.A. 2200

Perkin-Elmer PRS-10 Printer Sequencer

Perkin-Elmer AS-1 Auto Sampling System

Burner Control Box, P.E. No. 057-0262

Perkin-Elmer Hitachi 200 Recorder

Acetylene Gas Tank and Regulator

Argon Gas Tank and Regulator

Nitrous Oxide Gas Tank and Regulator

Inorganic 1000 ppm metal standards in matrix of dilute hydrochloric acid

Eppendorf micro-pipets

3. PROCEDURE, (Atomic Absorption Spectrophotometer) AAS:

Atomization Method - graphite furnace (except mercury)

Sample Matrix - 0.1 ml of Suprapur® HNO_3 in 50 ml of extractant water

Slit - Alternate

Gain — Set between 35 - 40 units

Source — Set to specifications of lamp being used

Signal — Absorbance

Mode — Continuous

Recorder - Absorbance

Background Corrector - AA (Background correction not used routinely)

Recorder Chart Expansion - Set as desired

The lamp is allowed its specified warm up time

Standards are made by adding appropriate aliquots of 1000 ppm standards to the correct matrix. Controls are made with the same matrix but with no exposure to plastics and no addition of the standard.

After proper alignment, each standard is analyzed at least two times. Following this, controls and samples are analyzed two times. Standards are interspersed in the analysis with a total standard frequency of no less than 5 percent of analysis time. Following the completion of the sample run, each standard is rerun. If the instrument response has changed, all questionable samples are rerun immediately followed by a series of standards.

4. METHODS:

Antimony (Sb):

Standards — 0.1, 0.05, 0.02 mg/l

Graphite Furnace Settings

	Temperature °C	*Time* Sec.
Dry	110	20
Char	825	22
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt — 3 sec.
Sample volume 20 2μl

Instrumental Parameters

- •Slit — 0.2 mm
- •Source — HCL, P.E. No. 303-6010
- •Wave length — 217.6 nm

Photometric Range - 0.5

Arsenic (As):

Standards — 0.100, 0.050, 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	20
Char	250	20
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt — 3 sec.
Sample volume 20 μl

Instrumental Parameters

- Slit — 0.7
- Source — EDL, P.E. No. 303-6211
- Wave length — 193.7 nm

Photometric Range - 0.5

Barium (Ba):

Standards — 0.100, 0.050, 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	23
Char	1100	36
Atomization	2700	5

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas flow reduction rate - 110 cc/min for 3 sec.
Sample volume — 20 μl

Instrumental Parameters

- Slit — 0.2
- Source — HCL, P.E. No. 303-6012
- Wave length — 553.6 nm

Photometric Range - 0.5

Cadmium (Cd):

Standards - 0.0100, 0.0050 0.0020 mg/l

Graphite Furnace Settings

	Temperature °C	Time, Sec.
Dry	110	20
Char	280	32
Atomization	2100	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 µl

Instrumental Parameters

•Slit - 0.2
•Source - HCL, P.E. 303 .601b
•Wave length - 228.8 nm

Photometric Range - 1.0

Chromium (Cr):

Standards - 0.100, 0.050 0.020 mg/l

Graphite Furnace Settings

	Temperature °C	Time, Sec.
Dry	110	20
Char	1100	32
Atomization	2700	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 µl

Instrumental Parameters

•Slit - 0.7
•Source - HCL, P.E. 303-6021
•Wave length - 357.9 nm

Photometric Range - 1.0

Lead (Pb):

Standards - 0.050, 0.030, 0.010 mg/l

Graphite Furnace Settings

	Temperature °C	*Time,* Sec.
Dry	110	20
Char	700	20
Atomization	2300	6

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- **Slit - 0.7**
- **Souce - HCL, P.E. 303-6111**
- **Wave length - 217.0 nm**

***Photometric Range* - 0.2**

Mercury (Hg):

***Sample Matrix* - sample water treated in accordance with Perkin-Elmer instructions for Mercury Analysis System No. 303-0830**

***Standards* - 0.010, 0.0050, 0.0020 mg/l**

***Atomization Method* - Perkin-Elmer Flameless Mercury Analysis System 303-0830**

Instrumental Parameters

- **Slit - 0.7**
- **Souce - HCL, P.E. 303-6044**
- **Wave length - 253.7 nm**

***Photometric Range* - 0.5**

Selenium (Se):

Standards - 0.050, 0.020, 0.0050 mg/l

Graphite Furnace Settings

	Temperature, °C	*Time, Sec.*
Dry	**110**	**20**
Char	**370**	**36**
Atomization	**2700**	**5**

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec.
Sample volume - 20 μl

Instrumental Parameters

- **Slit - 0.7**
- **Source - EDL, P.E. 303-6262**
- **Wave length - 196.0 nm**

***Photometric Range* - 0.2**

Tin (Sn):

***Standards* - 0.100, 0.050, 0.020 mg/l**

Graphite Furnace Settings

	Temperature °C	*Time* Sec.
Dry	110	30
Char	700	32
Atomization	2700	5

Purge gas - Argon
Purge gas flow rate - 300 cc/min
Purge gas interrupt - 3 sec
Sample volume - 20 μl

Instrumental Parameters

- Slit - 0.7
- Source - EDL, P.E. 303-6274
- Wave length - 224.6 nm

Photometric Range - 0.5

5. QUALITY CONTROL: Any liner sample which fails any chemical parameter is retested to assure that the problem is associated with the sample versus the analysis or analytical technique.

   In accordance with the 15th Edition of *Standard Methods for the Examination of Water and Wastewater,* the NSF laboratory utilizes two methods of quality control, internal and external. The internal method includes standard solutions and controls which correct for chemical interference in the extractant water. Standards and controls comprise 15% of the analytical time for heavy metals determinations; i.e., one in six randomly spaced controls.

   External quality control samples are analyzed on an average of once every three months, either as EPA reference standards or solutions of NSF extractant water spiked with metals at concentrations which approximate a "typical" liner sample. The quality control samples are prepared by personnel other than those involved in the analysis and are coded in a manner which simulates actual liner samples. The analyst receives the quality control sample, along with actual liner samples, with no knowledge of its status as a quality control sample.

B. TOTAL TRIHALOMETHANES (TTHM)

1. GENERAL: Total trihalomethanes (TTHM) [chloroform ($CHCl_3$) bromodichloromethane ($CHCl_2Br$) chlorodibromothane ($CHClBR_2$), and bromoform ($CHBr_3$)] in extractant water are determined using gas chromatography.

   10 ml of the sample's final exposure water are extracted with 2 ml of pentane and analyzed in accordance with the procedures outlined for the liquid/liquid extraction method (Federal Register/Vol. 44, No. 231/November 29, 1979, p. 68683).

   Three standards ranging from 5—100 ppb are prepared and then extracted in the same way. 4 μl of each are injected into the gas chromatograph equipped with a linearized electron capture detector. After calibration, 4 μl of each sample's extract are analyzed for TTHM content.

2. EQUIPMENT:

   Perkin-Elmer Sigma 3 B Gas Chromatograph

   Perkin-Elmer Sigma 10B Data Station

Perkin Elmer Auto Sampler (AS-100)

Electron Capture Detector (E.C.D.)

Column - 4 mm ID (6' x ¼" OD) 10% Squalane Chrom W-AW80/100 NOC

Nitrogen 4.5 grade

Compressed air Grade E

40 ml screw cap vials with Teflon faced silicone septa, Pierce #13075 and #13733

Sample vials with septa and aluminum seals for auto sampler

Extraction bottles and caps Sci/Spec #B 69110

Syringes
- 10, 25 and 100μl
- 5 and 10 cc with luer-lok tip

Gas stoppered volumetric - 25 and 100 ml

3. REAGENTS:

Pentane, suitable for TTHM GC analysis

Methanol, reagent grade

Chlorine reducing agent: Sodium thiosulfate

Standards
  Chloroform, reagent grade
  Bromodichloromethane, reagent grade
  Chlorodibromomethane, reagent grade
  Bromoform, reagent grade
  Carbon tetrachloride, reagent grade

Organic-free water[1]

4. INSTRUMENT PREPARATION:

Pneumatic Settings
  Carrier gas:
    Nitrogen - 80 psi
  Auto sampler:
    Air - 40 psi
    Nitrogen - 5 psi

Temperature Settings
  Oven - 67°C
  Injection port - 150°C
  Detector - 350°C

Total analysis time - 13 minutes

Flow rate through column - 70 cc/min plus 5 cc makeup.

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[1] Note: Organic-free water is defined as water free of interference when employed in the procedure described herein.

5. ANALYTICAL PROCEDURE

TTHM and CCl_4 are measured in accordance with the method for "Analysis of Trihalomethanes in Drinking Water by Liquid/Liquid Extraction," Federal Register/Volume 44, No. 231/November 29, 1979, p. 68683.

C. OTHER CHEMICAL PARAMETERS

1. PHENOLS: Phenols are measured in accordance with *Standard Methods for the Examination of Water and Wastewater,* 15th Edition, page 510 (4-aminoantipyrine method with preliminary distillation step).

2. TOTAL AVAILABLE RESIDUAL CHLORINE: Total available residual chlorine is measured in accordance with the method outlined in *Standard Methods for the Examination of Water and Wastewater*, 15th Edition, page 286 (Amperometric Titration Method, Procedure 4c).

Part 8

Ply Adhesion

ASTM D413 Section &. Procedure, Paragraph 9.1 Strip Specimens - Type A, 180 degree peel - . . .The next sentence shall be deleted and substituted in its place:

The cut strip shall be 1 inch wide measured to the nearest 0.01 inch.

ASTM D413 Section 12,Calculations, Paragraph 12.2 shall be modified to be:

For the machine method the value of adhesion is determined by taking the average of the five highest peaks shown on the autographic chart and is reported as the adhesion value as follows:

N/m (lbf/in) = force/actual width

If other than a 1 inch strip is tested show both the force and the actual width in the report.

Part 9

Accelerated Weathering Test

A. GENERAL

The test will be the Equatorial Mount with Mirrors for Acceleration plus water spray (EMMAQUA). Minimum specimen size will be 5 inches wide x 4 inches long. (Maximum width is 5 inches x 55 inches long within target area.)

Minimum number of specimens will be one for each FML type that is recommended for outdoor exposure.

The EMMAQUA Test machine is covered by U. S. patents. The testing service is provided by:

Desert Sunshine Exposure Test Inc.
Box 185
Black Canyon Stage
Phoenix, Arizona 85029

B. Exposure Rating Table

The following table rates the state of condition for the FML after exposure due to crazing.

Crazing is the phenomenon manifested by slight breaks or checks in the surface. The break should be called a "crack" if the underlying surface is visible. For precision evaluation, crazing is described as microscopic crazing as observed with a stated magnification of 10 power.

EXPOSURE RATING TABLE

Rating No.		Number of Checks[1]	Width of Checks[2]
9		S	Maximum
8	Microscopic	M	width
7	(10 X magnification)	L	.006 in.
6		S	Maximum
5	Naked eye at close range	M	width
4	(12 inches)	L	.015 in.
3		S	Not
2	Naked eye at distance	M	Acceptable
1	(3 feet)	L	
0	Complete failure		

[1] S = Small
M = Medium
L = Large

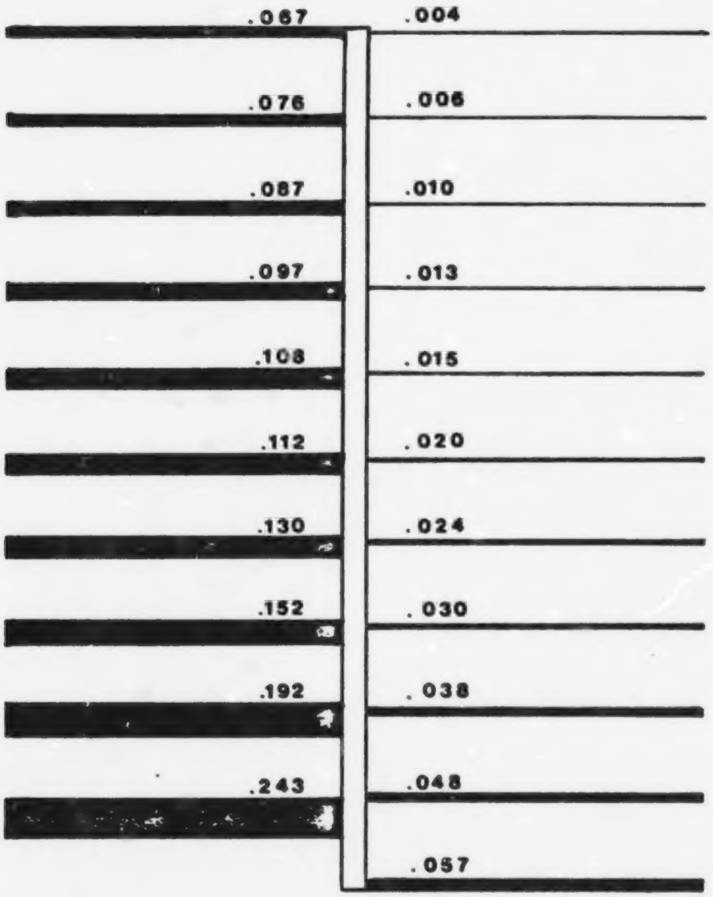
[2] When bent around ½ inch diameter mandrel.

Materials which have a rating of 7, 8 and 9 will be considered to have passed.

Materials which have a rating of 4, 5 and 6 will be required to make the proper corrections in the compound within three months after notification of the results and resubmitted for testing.

If, after the second submission, the material fails to obtain a minimum ranking of 7, the material in question will lose its NSF listing until such time the material meets the requirement.

A transparent crack width gauge, similar to that shown in Figure 1 along with a 10 power microscope may be used to measure the crack width.



CRACK WIDTH GAGE

.067
.004
.076
.006
.087
.010
.097
.013
.108
.015
.112
.020
.130
.024
.152
.030
.192
.038
.243
.048
.057

FIG.1

Part 10

Dead Load Seam Strength

A. Scope

To determine the ability of factory seam joints to withstand constant stress under load at room temperature (73°F).

B. Test Specimen

The supported specimen size shall be a 4-inch width of the seam joint and a 12-inch length, sufficient to fit in the clamps of the testing machine. The unsupported specimen size shall be a 1 inch width of the seam joint and an 8 inch length.

C. Procedure

The clamping mechanism will grip a 1 inch wide section and should be centered in the width of the test specimen, above and below the seam joint. The clamps shall not grip any portion of the overlap area of the seam joint.

1. Room Temperature Test: A designated load shall be applied to seam joint after it is fastened in the clamps. This load shall be equal to a percentage of the Bonded Seam Strength Value indicated in the Materials Properties Tables. The load shall be maintained for 4 hours at a temperature of 73°F. The stressed sample must be closely observed. Excessive elongation may require clamp adjustent to maintain consistent loading. When elongation reaches 50% of the original jaw separation, no additional adjustment need be made. Retain existing load for balance of test duration.

2. A "failure" will be noted when the seam joint separates entirely

D. Reporting of Results

The results shall be reported by indicating the designated load, the temperature, the time duration of the test, the length of the overlap seam, and a "pass" or "fail" designation.

PART 11

Dead Load Seam Strength at Elevated Temperature

A. Introduction

Sun exposure and high air temperatures sometimes result in the portion of an exposed FML above the water (or contained fluid) surface to reach temperatures over 120°F. If seams are improperly made and/or the FML material formula will not allow good seams to be made, then the lining may separate under temperatures and forces sometimes encountered in actual service. The dead load seam strength test at elevated temperature is designed to identify seams which are likely to be subjected to failure under such conditions.

The temperature selected for the test should be consistent with the thermal physical/chemical properties of the FML and the anticipated service condition. The temperature and load given in this test method may need to be revised. The FML material manufactuer should be consulted if changes in the test conditions appear appropriate.

B. Test Specimen

Unsupported Materials: The specimen shall be 1 inch wide, and at least 8 inches long. The seam shall be located in the center of the specimen and across the full width of the specimen.

Supported Materials: The specimen shall be 4 inches wide and at least 12 inches long. The seam shall be in the center of the specimen and across the full width of the specimen.

C. Procedure

The clamping mechanism will grip the full 1-inch width of an unsupported specimen. The grip separation shall be 4 inches plus the seam width.

A 1-inch wide section of a supported specimen in the center of the width of the test specimen should be gripped. The grip separation shall be 6 inches plus the seam width. The clamps shall not grip any portion of the overlap area of the seam joint.

The load equal to 25 percent of the required bonded seam strength should be applied to the seam joint after it is fastened in the clamps. The load shall be maintained for 4 hours at the temperature specified in the table for the particular material.

The stressed sample must be closely observed. Excessive elongation may require clamp adjustment to maintain consistent loading. When elongation reaches 50 percent of the original jaw separation, no additional adjustment need be made. Retain existing load for balance of test duration.

A "failure" will be noted when the seam joint separates entirely.

D. Reporting of Results

The results shall be reported by indicating the designated load, the temperature, the time duration of the test, the length of the overlap seam, and a "pass" or "fail" designation.

For example: 25 percent Bonded Seam Strength 158°F, 4 hours, 4 inch seam length, Pass.

Part 12

Environmental Stress Crack Resistance

ASTM D1693 shall be modified to be:

Condition C to be used with 100°C using 100% Igepal. Samples shall be 80 mils or finished product if thicker.

APPENDIX C

REPRESENTATIVE LIST OF ORGANIATIONS IN LINER INDUSTRY

POLYMERIC MEMBRANE LINERS

1. Polymer Producers
2. Manufacturers of Polymeric Membrane Sheeting
3. Fabricators of Liners
4. Installation Contractors

A POLYMERIC MEMBRANE LINERS

1. Polymer Producers

DOW CHEMICAL COMPANY
2040 Dow Center
P.O. Box 1847
Midland, MI 48640

Product Sales Manager,
Chlorinated Polyethylene Designed Products Department
Phone: 517-636-1000

D.I. du PONT de NEMOURS AND CO., INC.
Elastomer Chemicals Department
Wilmington, DE 19898

Contact: Bernard F. Anderson
Phone: 302-774-1000
Contact: Gerald E. Fisher
3707 Chevy Chase Road
Louisville, KY 40218
Phone: 502-459-8752

EXXON CHEMICAL CO.
Elastomer Technology Division
P.O. Box 45
Linden, NJ 07036

Contact:
Phone: 201-474-0100

HERCULES INCORPORATED
910 Market Street
Wilmington, DE 19899

Contact: Norman C. MacArthur
Phone: 302-575-6293

MONSANTO INDUSTRIAL CHEMICALS CO.
260 Springside Drive
Akron, OH 44313

Contact: Gary E. O'Connor
Project Manager
Commercial Development Department
Rubber Chemicals Division
Phone: 216-666-4111

PANTASOTE, INC.
26 Jefferson Street
Passaic, NJ 07055

Contact: Dr. R. Brookman
Phone: 201-777-8500

POLYSAR, LTD.
Technical Development Division
Vidal Street
Sarnia, Ontario
Canada N7T 7M2

Contact: John Redland
Phone: 519-337-8251

SHELL CHEMICAL COMPANY
605 N. Main Street
Altamont, IL 62411

Contact: Larry Watkins
Phone: 618-483-6517

UNIROYAL CHEMICAL COMPANY
Spencer Street
Naugatuck, CT 06488

Contact: Allen Crepeau
Phone: 203-723-3825

2. Manufacturers of Polymeric Membrane Sheetings

*BURKE RUBBER COMPANY
2250 South Tenth Street
San Jose, CA 95112

Contacts: D. Kutnewsky
Manager, Flexible Membranes

Mr. Doug Bartlett

Phone: 408-297-3300

*CARLISLE TIRE AND RUBBER CO.
Construction Materials Department
P.O. Box 99
Carlisle, PA 17013

Contact: Hugh Kenney
Phone: 717-249-1000

COLUMBUS COATED FABRICS
1280 N. Grant Street
Columbus, OH 43216

Contact: Lee Fishbein
Phone: 614-225-6069

COOLEY, INC.
50 Esten AVenue
Pawtucket, RI 02862

Contact: Paul Eagleston, Vice President
Phone: 401-724-9000

DUNLINE LIMITED
(A Dunlop Company)
160 Eglinton Avenue East
Toronto, Ontario
Canada M4P 1G3

Contact:
Phone: 416-487-1114

GACO
P.O. Box 88698
Seattle, WA 98188

Contact: Earle Johnson
San Jose, CA
Phone: 415-341-5661

*B.F. GOODRICH COMPANY
Engineered Rubber Products Division
500 S. Main Street
Akron, OH 44318

Contacts: R.D. Cunningham, Sales Manager
Environmental Products

Mr. C. Marcot

Phone: 216-379-2226

GUNDLE PLASTICS, INC.
5340 Alpha Road, Suite 101
Dallas, TX 57520

Contact: Richard K. Schmidt
Phone:

HART & COMPANY
16 E 34th Street
New York, NY 10016

Contact: R.H. Dickinson
Phone: 212-481-1210

KOKOHU, USA, INC.
P.O. Box 2287
Everret, WA 98203

Contact: Ms. Miki Makamura
Phone: 806-353-7000

MAINLINE, INC.
3292 South Highway 97
Redmond, Or 97756

Contact: DeWitt Maine
Phone: 503-548-4207

PANTASOTE, INC.
26 Jefferson Street
Passaic, NJ 07055

Contact: Dr. R. Brookman
201-777-8500

PLYMOUTH RUBBER COMPANY
104 Revere Street
Canton, MA 02021

Contact: Charles Neese
Phone: 617-828-0220

REEVES BROS., INC.
Vulcan Coated Fabrics Division
P.O. Box 431
Rutherford, NC 28139

Contact: Walter McEvilly, Vice President
Sales and Marketing
Phone: 704-286-9101

*SCHLEGEL LINING TECHNOLOGY, INC.
P.O. Box 7730
The Woodlands, TX 77380

Contact: James M. Price, President
Mr. Morris Jett
Phone: 713-273-3066 (Conroe)
713-350-1813 (Houston)

SEAMAN CORP.
P.O. Box 11007
Charlotte, NC 28209

Contact: Jack Watson
Phone:

SHELTER-RITE, INC.
P.O. Box 331
Millersburg, OH 44654

Contact: Dr. Bala Venkataraman, Vice President
Research and Development
Phone: 216-674-2015

STAUFFER CHEMICAL CO.
4407 S. Broad Street
Yardville, NJ 08620

Contact: William F. Christie
Technical Manager
Phone: 201-549-6880

*STEVENS ELASTOMERIC & PLASTICS PRODUCTS, INC.
27 Payson Avenue
Easthampton, MA 01073

Contact: Arnold G. Peterson
Phone: 413-527-0700

TENNECO CHEMICALS, INC.
P.O. Box 189
Piscataway, NJ 08805

Contact: Bob Hayes/Kent Turner
Phone: 201-356-2550

UNIROYAL, INC.
312 N. Hill Street
Mishawaka, IN 46544

Contact: D.L. Zimmerman
Phone: 219-256-8181

3. Fabricators of Liners

BROWN AND BROWN
P.O. Drawer 269
Mobile, AL 36601

Contact: Sam Brown, President
Phone: 205-479-6581

ELECTRA TARP, INC.
Park Centre
7241 Whipple Avenue, N.W.
North Canton, OH 44720

Contact: Bob Fulmer, President
Phone: 216-497-1496

ENVIRONETICS, INC.
9824 Industrial Drive
Bridgeview, IL 60455

Contact: Ray Winters, President
Phone: 312-585-6000

FABRICO MANUFACTURING CORP.
1300 West Exchange Avenue
Chicago, IL 60609

Contact: Jay Sabath, Sales Manager
Phone: 312-254-4211

MCKITTRICK MUD CO.
P.O. Box 3343
Bakersfield, CA 93305

Contact: Bill Wheeler, President
Phone: 805-325-5013

*PALCO LININGS, INC.
7571 Santa Rita Circle
P.O. Box 919
Stanton, CA 90680

Contacts: Richard Cain, Senior Vice President
Mr. W. Bachelder
Phone: 714-898-0867

POLY-PLASTICS
P.O. Box 299
Springfield, OH 45501

Contact: Roland Harmer, President
Phone: 513-323-4625

PROTECTIVE COATING, INC.
1602 Birchwood Avenue
Ft. Wayne, IN 46803

Contact: Elmo Murrell, President
Phone: 219-422-7503

M. PUTTERMAN & CO.
2221 West 43rd Street
Chicago, IL 60609

Contact: A. Berman, President
Phone: 312-927-4120

REVERE PLASTICS
16 Industrial Avenue
Little Ferry, NJ 07643

Contact: Larry Smith, President
Phone: 201-641-0777

SOUTHWEST CANVAS MFG. CO.
Oklahoma City, OK

Contact: Richard C. Nelson, Manager
Phone: 405-672-3355

*STAFF INDUSTRIES
240 Chene Street
Detroit, MI 48207

Contacts: Charles E. Staff, President
Mr. R.G. MacDonald
Phone: 313-259-1820
800-526-1368

*SYNFLEX INDUSTRIES INC.
2004-750 Jervis Street
Vancouver, British Columbia
Canada V6E 2A9

Contacts: Gerald W. Salberg, President
Mr. R.S. Atkinson
Phone: 604-682-3621

*WATERSAVER COMPANY, INC.
P.O. Box 16465
Denver, CO 80216

Contacts: Bill Slifer, Vice President
James B. Bryan
Phone: 303-623-4111

MANUFACTURERS WHO ALSO FABRICATE

Burke Rubber Company
Carlisle Tire and Rubber Co.
B.F. Goodrich
Schlegel Area Sealing Systems, Inc.

4. Installation Contractors

CRESTLINE SUPPLY CORP.
2987 South and 300 West
Salt Lake City, UT 84115

Contact: Guy Woodward
Phone: 801-487-2233

ENVIROCLEAR, INC.
P.O. Box 242
Falls Village, CT 06031

Contact: Don Thompson, President
Phone: 212-997-0100
518-325-3332

AL GASTON CONSTRUCTION CO., INC.
Gaston Containment Systems
P.O. Box 1157
El Dorado, KS 67042

Contact: John Saens
Phone: 316-321-5140

*GLOBE LININGS, INC.
1901 East Wardlow Road
Long Beach, CA 90807

Contacts: William Kays
Mr. R. Webb

Phone: 213-426-2587
213-636-6315

GULF SEAL CORPORATION
601 Jefferson
534 Dresser Tower
Houston, TX 77002

Contact: Howard S. Dial, Division Vice President
Phone: 713-782-9220

MAY ENTERPRISES, INC.
P.O. Box 6606
Odessa, TX 79760

Contact: Ken Stewart, President
Phone: 915-362-2368

MWM CONTRACTING CORP.
347 North Main Street
Milford, MI 48042

Contact: Joe McCullough
Phone: 313-685-9350
313-685-1201

NATIONAL SEAL CO., INC.
7701 East Kellogg
Wichita, KS 67202

Contact: John W. Owen
Phone: 316-681-1931

PACIFIC LININGS, INC.
P.O. Drawer GGGG
Indio, CA 92201

Contact: John Blatt, President
Phone: 714-347-0828

PLASTI-STEEL, INC.
3588 West 13th Street
Vickers-KSB&T Building
Wichita, KS 67203

Contact: M.C. Green, President
Phone: 316-262-6861

SCHLEGEL AREA SYSTEMS, INC.
P.O. Box 23197
Rochester, NY 14692

Contact: James M. Price
Phone: 716-244-1000

5

STA-FLEX CORP.
16 Post Road
Greenland, NH 03840

Contact: Lou Peloquin
4917 New Ramsey Court
San Jose, CA 95136
Phone: 408-224-0604

THE THURSTON WALLCE CO.
5470 East Evans Avenue
Denver, CO 80222

Contact: Hank Thurston, President
Phone: 303-758-2232

TRI STATE CONSTRUCTION
959 108th Avenue, N.E.
Belleview, WA 98004

Contact: Joe Agostino
Phone: 206-455-2570

UNIT LINER CO.
P.O. Box 789
Shawnee, OK 74884

Contact: J.A. Hendershot, President
Phone: 405-275-4600

UNIVERSAL LININGS, INC.
P.O. Box 315
Haverford, PA 19041

Contact: David M. Small, President
Phone: 215-649-3600

FABRICATORS WHO ALSO INSTALL:

McKittrick Mud
Synflex Industries, Inc.

APPENDIX D

LINER SUPPLIERS

APPENDIX D-1

QUESTIONNAIRE TO LINER SUPPLIERS

Attached letter mailed to:

Schelegel Lining Technology Inc.
232 Parkland Crescent S.E.
Calgary, Alberta
Mr. R.J. Thomson

Huron Lining Technology Ltd.
711 Robertson Crescent
Milton, Ontario
L9T 4W2
Mr. R.J. Lewington

Lexcan Limited
85 Vulcan Street
Rexdale, Ontario
M9W 1L4
Mr. Dominique Petruzzi

Dunlop Industrial Limited
Dunline Division
Building #84
P.O. Box 543
Huron Park, Ontario
N0M 1Y0
Mr. Carl Hannigan

Staff Linings Inc.
4220 Mitchell Crescent
Windsor, Ontario
N6G 2G2
Mr. Ed Staff

Gundle Lining Systems Inc.
301-255 1st Street West
North Vancouver, B.C.
V7M 3G8
Mr. Jerry Slaberg

Gundle Lining Systems Inc.
Gundle Road
1340 East Richey Road
Houston, Texas
77073
Mr. Paul Barker

Watersaver Company Inc.
5870 East 56th Avenue
Commerce City, Colorado
80022
Mr. James B. Bryan

Palco Linings Inc.
7571 Santa Rita Circle
P.O. Box 919
Stanton, California
90680

Burke Rubber Company
2250 South Tenth Street
San Jose, California
95112
Mr. Robert Woodley

Globe Linings Inc.
1901 East Wardlow Road
Long Beach, California
90807
Mr. W. Kays

J.P. Stevens & Co. Inc.
Elastomeric Products Departmen
East Hampton, Mass.
01027
Mr. Arnold G. Peterson

Butyl Products Limited
Radford Crescent
Billericay - Essex
England

Dunlop Construction Products I
2055 Flavelle Boulevard
Mississauga, Ontario
L5K 1Z8
Attention: Mr. Robert Rayfiel
(March 30, 1984)

Dow Chemical Canada
Modeland Road Research Centre
P.O. Box 1012
Sarnia, Ontario
N7T 7K7
Mr. J. Sabzali
(April 2, 1984)

April 2, 1984 Our ref: 841-3015

RE: FLEXIBLE MEMBRANE (POLYMERIC) LINERS
AS LONG-TERM BARRIERS FOR URANIUM MILL TAILINGS

Dear Sirs:

Golder Associates is conducting Phase I of an evaluation of flexible membrane liners for use as uranium tailings pond liners and dam membranes. The study is being carried out for Energy, Mines and Resources, Canada as part of the National Uranium Tailings Program.

Phase I of the study will be based on available published information, information from suppliers and information from industrial users. Phase II of the study, which is not yet approved, will involve a laboratory test program to study failure mechanisms, degradation rates and contaminant release rates through liners selected as a result of the Phase I study.

For the purpose of the study it will be assumed that the liners will be provided with soil cover and that the time of consideration will be up to 1000 years following installation.

The two main areas of Canada to be considered will be the Key Lake area of Northern Saskatchewan and the Elliot Lake area of Ontario.

... 2

At present we are considering the following polymeric liners:

i) HDPE
ii) CPE
iii) CSPE (Hypalon)
iv) PVC
v) EPDM
vi) PE
vii) Butyl rubber
viii) Neoprene
ix) Polyurethane

Please forward an up-to-date information package corresponding to the above materials which you supply. We would specifically request information corresponding to the categories identified in the attached checklist. It is anticipated that some of the information would be included in your standard brochures, however, additional information will likely be required.

Please note that we do not require detailed design or exact cost estimates at this time. The cost information requested is to establish orders of magnitude to compare the various liner materials; it will not be used to compare the liner manufacturers or suppliers.

Responses from manufacturers/suppliers will be incorporated in the Phase I report.

Due to the project timing constraints, we would appreciate a written response as soon as possible.

Should you have any questions, please contact the undersigned in our London office.

Yours truly

GOLDER ASSOCIATES

Frederick W. Firlotte, P. Eng.
Associate

FWF/jl
Att.

INFORMATION REQUIRED FOR PHASE I OF THE STUDY

1) PHYSICAL PROPERTIES

i) tensile strength
ii) puncture resistance
iii) tear resistance
iv) abrasion resistance
v) dimensional stability
vi) flexibility
vii) creep resistance
viii) permeability

2) CHEMICAL COMPATIBILITY

i) In contact with uranium tailings (if available).
  - extraction process is sulphuric acid leaching, solvent extraction solution purification and ammonia solvent stripping.
ii) oxidizing acid resistance
iii) mild acid resistance
iv) base resistance
v) general chemical resistance
vi) resistance to hydrocarbons (aromatic and non-aromatic)
vii) volatility
viii) bacterial resistance

3) PERFORMANCE CHARACTERISTICS

i) ozone resistance
ii) ultraviolet resistance
iii) low temperature performance including freeze-thaw
iv) high temperature performance
v) potential for cracking
vi) provide any information on hand associated with design life (note uranium tailings application)

4) INSTALLATION

i) describe recommended installation procedures and site preparation required
ii) indicate effects of weather/climate
iii) indicate required/recommended field seaming technique and comment on reliability
iv) comment on resistance to equipment damage during installation
v) indicate maximum recommended slope inclination for liner installation

5) TESTING

i) indicate capabilities and location of testing facilities, if any
ii) describe routine quality control during fabrication
iii) describe field seam testing techniques during installation
iv) provide results of any compatibility testing including accelerated testing carried out and which is not confidential (note uranium tailings application)
v) provide information associated with radiation damage to liner material (if available)

6) COMPANY INFORMATION

i) describe services offered (ie. resin manufacture, calendering/extrusion, installation)
ii) indicate your largest single sheet capability
iii) indicate location of your plant facilities
iv) indicate what quarantees or follow-up you would typically provide

7) PREVIOUS EXPERIENCE

i) indicate previous experience with liners for uranium tailings anywhere in world including Canada
(size, location, owner, year installed, what contained, and any comments associated with installation and performance)
ii) previous experience with liners for mining indistry in Canada (same information as 7 i))
iii) previous experience with liners for hazardous waste facilities in Canada (same information as 7 i))

8) MONITORING (Case Histories)

i) provide any information available associated with performance of liners based on monitoring of installations (contaminant release rates/ quantities, liner size, type of monitoring system, material contained)
ii) provide any information available which describes performance of liners, in general, following installation (note uranium tailings application)

9) COSTS

i) estimate 1984 cost range for liners for the two areas of interest noted:

a) Elliot Lake-Blind River area of Ontario, Canada
b) Southeast Athabaska Region (Key Lake, Midwest Lake, Cluff Lake, Rabbit Lake -Collins Bay) of Northern Saskatchewan

ii) costs should represent installed cost per square foot (or metre) for a large installation (say 1,000,000 ft^2). Please indicate if earthworks and soil cover is included.

iii) If available we would be grateful for any of the component costs such as:

- sheet supply
- shipping
- field seaming

APPENDIX D-2

SUMMARY OF SUPPLIERS' RESPONSES

APPENDIX D-2-1

GUNDLE LINING SYSTEMS

Gundle Lining Systems Ltd.

Gundle

301-255 1st Street West
North Vancouver,
B.C. Canada
V7M 3G8

Telex:
GUNDLE-VCR
04-352815
Tel. (604) 980-8337

GUNDLINE HIGH DENSITY POLYETHYLENE FLEXIBLE MEMBRANES

We are pleased to submit information on Gundle Lining Systems products and services relating to the engineered flexible membrane lining industry.

For over seventeen years we have manufactured, furnished, or installed most commonly known synthetic membrane materials, ranging from thin PVC through medium-strength synthetic rubber, to extra heavy duty Digh Density Polyethylene (HDPE) sheeting. We currently offer our GUNDLINE HD (High Density) Polyethylene sheeting in standard widths of 22.5 feet without any factory seams in thicknesses ranging from 20 to 100 mils. Common applications for GUNDLINE include basins, ponds, lagoons, reservoirs, canals, leaching pads, waste disposal areas, or any application where a high-reliability permanent barrier is required.

The Gundle Company is fully integrated with respect to Manufacturing, Research and Development for special applications, construction and supervisory capabilities having installed over 70 million square feet of assorted lining materials during the past 17 years.

Gundle can efficiently meet your containment needs with a chemically-compatible material of suitable thickness, professionally installed to achieve a secure and cost effective containment system.

We hope that you find the enclosed information of interest. Please contact us for additional information.

Sincerely,

G.W. Salberg, P. Eng.
President

Enclosure

Gundle Lining Systems Ltd.

Gundle

301-255 1st Street West
North Vancouver,
B.C. Canada
V7M 3G8

Telex:
GUNDLE-VCR
04-352815
Tel. (604) 980-8337

GOLDER ASSOCIATES
MAR [illegible] 1984
RECEIVED — LONDON

March 2, 1984

Mr. Frederick W. Firlotte, P. Eng.
GOLDER ASSOCIATES (EASTERN CANADA) LTD.
500 Nottinghill Road
LONDON, Ontario
N6K 3P1

Dear Mr. Firlotte:

RE: FLEXIBLE MEMBRANE (POLYMERIC) LINERS
AS LONG TERM BARRIERS FOR URANIUM MILL TAILINGS
PHASE I STUDY

We are pleased to submit information on our Gundline High Density Polyethylene liners and Gundle Fusion Welding System to assist you in preparing Phase I of the above study.

We have followed the format you laid out and specifically provide in house or other test reports and specifications to answer your questions. Due to the urgency of your request we have had to supply information in photocopy style, should you have any difficulty following a specific item please call us for clarification.

Information provided:

1. Physical Properties	Information Provided
i) Tensile	Gundle standard specification NSF/EPA standard
ii) Puncture	Matrecon Report 9/22/83
iii) Tear	Gundle standard specification
iv) Abrasion	Gundle standard specification

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Page 2 Continued

v) Dimensional stability	Gundle standard specification
vi) Flexibility	Gundle standard specification
vii) Creep Resistance	Schlegel excerpt
viii) Permeability	Woodward Clyde Report 9/16/83 Salberg Report 12/5/83
2. Chemical Compatability	
i) Uranium Tailings	Battelle NW Report 2/27/84 Matrecon Report Nuclear Liquid 3/12/82 Matrecon Leach Report 9/17/81
ii to vii)	Gundle Report 156 11/23/82 210 3/23/83 216 4/04/83 111 10/27/82 185 3/02/83 Gundle Report 4/29/82 Matheson Gundle Chemical Resistance Bulletin NSF Report under Gundle memo 2/13/84
viii) Bachterial Resistance	U.S. Testing Report 3/4/81
3. Performance Characteristics	
i) Ozone	Gundle standard specification Case Report 10/23/80
ii) U.V. Resistance	CIL Report 1983

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Page 3 Continued

iii)	Low Temperature	Gundle Lab Report Shrinkage 4/83 Gundle Lab Report 443 U.S. Testing Report 8/12/82
iv)	High Temperature	Gundle Lab Reports 145 10/17/82 160 10/17/82
v)	Cracking	Gundle Lab Report 200 2/13/84 Gundle Lab Report 313A 10/3/83
vi)	Coefficient of Friction	R.K.S. Report 8/18/81
4.	Installation	
i)	Recommended Procedure	Gundle standard specification Gundle Technical Report 100 7/83
ii)	Effects Climate (Installation only- service ok all condition)	Min. installation period temperature for welding 0°C Min. operating temperature (not relevant) Shut down installation during high winds 50 kmph, rain/snow
iii)	Beaming	See Section 5
iv)	Damage	2.0-2.5mm thick very resistant mechanical damage - rubber tired equipment can run over 1.0-1.5 no recommended for vehicle traffic
v)	Slope Inclination	Vertical to any flatter slope

..... 4

Page 4 Continued

5.	Testing	
i)	Capabilities	All tests as shown on standard specification plus environmental chamber to -50° + 100° at Houston plant
ii)	Quality Control	Gundle QC manual Jan. 84
iii)	Field Seaming	Gundle Fusion Welding manual Welding Institute report 1/9/84
iv)	Compatability	NSF Report 2/13/84
v)	Radiation	N/A
6.	Company Information	
i)	Services	R & D Engineering Extrusions Installation
ii)	Sheet Size	Page 2 Gundle standard specification
iii)	Location	Houston, Texas Gundle Lining Review Vol. 1 No. 1 Jan. 82 Vol. 1 No. 2 Kansas reprint Saudi report
iv)	Guarantees	Sample warranty 20 year pro-rata

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Page 5 Continued

7. Previous Experience

i) Uranium Tailing Liner	Rossing report 1974
ii) Mining Experience	Project reference lists Canada, U.S.A., South Africa
	Gundle Lining Review Vol. 1 No. 1 Dawn Mining
iii) Other Experience	Project reference as in ii
	Lavalin Report Jan. 84
	Matrecon Report Feb. 81

8. Monitoring	No available information

9. Costs (Union Labour) - Tailing Dam Slope (Facing)

i (a) 2.0mm HDPE 1984 Installed Elliot Lake Blind River	$12.00 - 12.50 sq.m.
2.5mm HDPE	$13.50 - 14.00 sq.m.

Tailing Floor or Water Reservoir

2.0mm HDPE	$10.50 - 11.00 sq.m.
2.5mm HDPE	$11.50 - 12.00 sq.m.

N. Saskatchewan add 5%.

No earthwork or soil cover

Key Lake 2.5mm actual $14.00 sq.m.

Federal Sales Tax / Provincial Sales Tax included

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Page 6 Continued

By percentage:

Material - 63% including FST
Shipping - 4%
Field Installation - 33%

I trust the foregoing information is satisfactory, however if you should require any further information please do not hesitate to contact me.

Yours very truly,

GUNDLE LINING SYSTEMS LTD.

G.W. Salberg, P. Eng.
President

GWS/dlj
Encls.

SPECIFICATIONS

Gundline® HD

High Density Polyethylene

PROPERTY	TEST METHOD	GAUGE (NOMINAL)					
		0.5mm	0.75mm	1.0mm	1.5mm	2.0mm	2.5mm
Density (g/cc) (Minimum)	ASTM D1505	0.94	0.94	0.94	0.94	0.94	0.94
Minimum Tensile Properties (Each direction)	ASTM D638 Type IV Dumb-bell at 2 ipm.						
1. Tensile Strength at Break N/25 cm		356	534	712	1068	1424	1780
2. Tensile Strength at Yield N/25 cm		222	311	422	622	844	1068
3. Elongation at Break (Percent)		700	700	700	700	700	700
4. Elongation at Yield (Percent)		13	13	13	13	13	13
5. Modulus of Elasticity MPA	ASTM D882	760	760	760	760	760	760
Tear Resistance Initiation N	ASTM D1004 Die C	66	98	132	198	264	330
Low Temperature	ASTM D746 Procedure B	−40°C	−40° C	−40°C	−40° C	−40°C	−40° C
Dimensional Stability (Each direction, percent change maximum)	ASTM D1204 212°F 1 hr.	±2	±2	±2	±2	±2	±2
Volatile Loss (Maximum %)	ASTM D1203 Method A	0.1	0.1	0.1	0.1	0.1	0.1
Resistance to Soil Burial (Percent change maximum in original value) Tensile Strength and Elongation at Break and Yield	ASTM D3083 using ASTM D638 Type IV Dumb-bell at 2 ipm.	±10	±10	±10	±10	±10	±10
Ozone Resistance	ASTM D1149 7 days 100 pphm, 104°F. Magnification	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×	No cracks 7×
Environmental Stress Crack (Minimum hours)	ASTM D1693	750	750	750	750	750	750
Puncture Resistance N	FTMS 101B	378	600	778	1200	1556	1957
Water Absorption (% Weight change)	ASTM D570	0.1	0.1	0.1	0.1	0.1	0.1
Hydrostatic Resistance MPA	ASTM D751 Method A Procedure I	1.1	1.65	2.17	3.38	4.48	5.59

Gundle Lining Systems, Inc., 1340 East Richey Road
Houston, Texas 77073 USA Phone (713) 443-8564
USA Telex – 792804 GUNDLE HOU
International Telex – 6868205 GUNDLE HOU

In Canada contact: Gundle Lining Systems, Ltd.
301-255 1st Street West, North Vancouver, BC V7M 3G8
Phone (604) 980-8337 Telex-04-352815

Gundle®

The advanced technology lining system.

Gundline® HD

High Density Polyethylene

GUNDLINE-HD is a high quality formulation of High Density Polyethylene containing approximately 97.5% polymer and 2.5% of carbon black, anti-oxidents and heat stabilizers. The product was designed specifically for exposed conditions. It contains no additives or fillers which can erode the product over time.

JOINING SYSTEM

Critical to the success of any flexible membrane liner is the joining system. Gundle's patented Fusion Welding Process is used to join individual panels of GUNDLINE-HD. Request your copy of the Gundle Fusion Welding bulletin for complete details.

CHEMICAL RESISTANCE

GUNDLINE-HD is resistant to a wide range of chemicals including acids, alkalis, salts, alcohols, amines, oils, and hydrocarbons. Since combinations of chemicals of different concentrations and temperatures have different characteristics, consult Gundle for specific application details. Write for Gundle's chemical compatibility information.

SUPPLY SPECIFICATION

The following describes standard roll dimensions for GUNDLINE-HD.

THICKNESS		WIDTH		LENGTH		AREA		ROLL WEIGHT	
(mil.)	mm.	ft.	m.	ft.	m.	ft.²	m.²	lb.	kg.
20	0.5	22.5	6.75	1250	381	28,125	2613	2800	1272
30	0.75	22.5	6.75	840	256	18,900	1756	2800	1272
40	1.0	22.5	6.75	650	198	14,625	1359	2800	1272
60	1.5	22.5	6.75	420	128	9,450	878	2800	1272
80	2.0	22.5	6.75	320	100	7,145	664	2800	1272
100	2.5	22.5	6.75	250	76	5,582	519	2800	1272

GUNDLINE-HD is rolled on 150mm hollow cores.
Each roll is provided with 2 slings to aid handling on site.
Dimensions and weights are approximate. Custom lengths available on request.

CHEMICAL RESISTANCE BULLETIN

GUNDLINE® –HDA
GUNDLINE® –HD
GUNDLINE® –DRI
GUNDLINE® –HYP

In order to provide a guide for engineers seeking suitable plastic membranes for lining applications, this resistance guide has been tabulated from information both obtained from our own laboratories, as well as from a variety of other sources.

Our range of plastics are primarily inert, particularly stable, and contain no plasticizers. They exhibit a resistance to a wide range of chemicals. Chemical resistance refers to the liners' ability to withstand two main kinds of attack by chemicals. The one is their resistance to chemical attack and the other relates to their resistance to absorption and swelling and consequent weakening.

It is important to note that mixtures of chemicals do not necessarily have the same effect or lack of effect on a plastic than do each of the individual components. Chemical attack can be influenced by temperature, contact time, concentration and composition. **It is recommended that immersion tests be carried out at the design stage of the project in order to confirm the suitability of the type of membrane selected.**

GUNDLINE® –HDA is a proprietary elastomeric polyolefin alloy based on high density polyethylene. It is semi-flexible, extremely tough and offers excellent puncture resistance. It contains anti-oxidants, heat stabilizers, UV inhibitors and carbon black to provide outstanding weathering characteristics.

GUNDLINE® –HD is an unmodified high density polyethylene. It is extremely resistant to chemicals and oils, highly puncture resistant and rigid. It contains a long lasting stabilizer to provide durable outdoor exposure.

GUNDLINE® –DRI is a flexible proprietary formulation, containing co-polymer low density polyethylene with anti-oxidants, carbon black, heat stabilizers and UV inhibitors.

GUNDLINE® –HYP is a specially designed formula based on an ethylene vinyl acetate stabilized co-polymer. It is very flexible and has excellent elastic properties and is highly puncture resistant. It is normally used in covered applications.

CHEMICAL RESISTANCE RATING GUIDE — DATA BASED ON IMMERSION AT 25°C (77°F)

O — No effect
M — Moderate effect
S — Severe effect

	[illegible]	[illegible]	[illegible]	[illegible]
WATER				
Distilled Water	O	O	O	O
Sea Water — Atlantic	O	O	O	O
Sea Water — Pacific	O	O	O	O
INORGANIC ACIDS				
Boric Acid (10%)	O	O	O	O
Chlorosulphonic Acid (10%)	S	S	S	S
Chromic Acid (10%)	M	S	S	O
Chromic Acids (Conc.)	S	S	S	M
Hydrochloric Acid (10%)	O	O	O	O
Hydrochloric Acid (Conc.)	O	M	M	O
Hydrofluoric Acid (Conc.)	O	M	M	O
Nitric Acid (10%)	O	O	O	O
Phosphoric Acid (Conc.)	O	M	O	O
Sulphuric Acid (10%)	O	O	O	O
Sulphuric Acid (Conc.)	M	M	M	M
INORGAN[illegible]				
Ammon[illegible]0%)	O	O	O	O
Am[illegible]nc.)	O	O	O	O
[illegible])	O	O	O	O
C[illegible] (10%)	O	O	O	O
Pota[illegible]m Hydroxide (10%)	O	O	O	O
Sodium Hydroxide (10%)	O	O	O	O
Sodium Hydroxide (Conc.)	O	O	O	O
INORGANIC SALTS (25% Solutions)				
Aluminium Chloride	O	O	O	O
Aluminium Sulphate	O	O	O	O
Ammonium Chloride	O	O	O	O
Ammonium Nitrate	O	O	O	O
Ammonium Phosphate	O	O	O	O

	[illegible]	[illegible]	[illegible]	[illegible]
Barium Chloride	O	O	O	O
Barium Sulphide	O	O	O	O
Calcium Chloride	O	O	O	O
Calcium Hypochlorite	O	O	O	O
Cupric Chloride	O	O	O	O
Cupric Sulphate	O	O	O	O
Ferric Chloride	O	M	O	O
Ferric Nitrate	O	M	O	O
Ferrous Sulphate	O	O	O	O
Magnesium Chloride	O	O	O	O
Magnesium Sulphate	O	O	O	O
Nickel Sulphate	O	O	O	O
Potassium Chloride	O	O	O	O
Potassium Permangenate	O	S	O	O
Potassium Bisulphite	O	O	O	O
Potassium Dichromate	O	O	O	O
Sodium Borate (Borax)	O	O	O	O
Sodium Bicarbonate	O	O	O	O
Sodium Chloride	O	O	O	O
Zinc Chloride	O	O	O	O
Zinc Nitrate	O	O	O	O
Sodium Chloride — Saturated	O	O	O	O
ORGANIC ACIDS				
Acetic Acid (10%)	O	O	O	O
Acetic Acid (Glacial)	M	O	M	O
Chloracetic Acid (10%)	O	O	O	O
Citric Acid (10%)	O	O	O	O
Formic Acid (10%)	O	O	O	O
Lactic Acid (10%)	O	O	O	O
Oleic Acid (100%)	M	S	S	O
Oxalic Acid (10%)	O	O	O	O

Gundle
Gundle Lining Systems Inc.
Gundle Road 1340 E. Richey Rd.
Houston, Texas 77073 (713) 443-8564

	[illegible]	[illegible]	[illegible]	[illegible]
Phenol (10%)	O	M	M	O
Phenol (100%)	M	S	S	O
Picric Acid (10%)	M	O	O	O
Stearic Acid (100%)	M	O	O	O
Tannic Acid (10%)	O	O	O	O
Tartaric Acid (10%)	O	O	O	O
ALCOHOLS				
Benzyl Alcohol	M	S	S	O
Ethyl Alcohol	O	O	M	O
Isopropyl Alcohol	O	O	M	O
Methyl Alcohol	O	O	M	O
Ethylene Glycol	O	O	O	O
Methyl Ethyl Ketone	O	S	M	O
Methyl Isobutyl Ketone	O	S	S	O
Glycerol	O	O	O	O
I-Hexanol	O	O	O	O
Resorcinol	O	O	O	O
ALDEHYDES				
Benzaldehyde	M	S	S	O
Butraldehyde	M	S	S	O
Furfural	O	S	S	O
AMINES				
Aniline	O	S	S	O
Triethanolamine	O	S	M	O
ESTERS				
Amyl Acetate	M	S	S	O
Dibutyl Sebacate	M	S	M	O
Dioctyl Phthalate	M	S	M	O
Ethyl Acetate	M	S	M	O
Tricresyl Phosphate	M	S	M	O
ETHERS				
Dibenzyl Ether	M	S	S	M
Diethylene Glycol Monobutyl Ether	M	S	S	M
Ethyl Ether	S	S	S	M
Ethylene Glycol Monoethyl Ether	M	S	S	M
HYDROCARBONS				
Benzene	S	S	S	M
Cyclohexane	S	S	S	O
Ethylbenzene	S	S	S	M
Heptane	S	S	S	M
Hexane	S	S	S	M
Napthalene	S	S	S	O
Toluene	S	S	S	M
Xylene	S	S	S	M
HALOGENATED HYDROCARBONS				
Benzyl Chloride	S	S	S	S
Bromobenzene	S	S	S	S
Carbon Tetrachloride	S	S	S	M
Chloroform	S	S	S	S
Ethylene Dichloride	S	S	S	S
Perchloroethylene	[illegible]	[illegible]	[illegible]	[illegible]

	[illegible]	[illegible]	[illegible]	[illegible]
OTHER SUBSTITUTED HYDROCARBONS				
Carbon Disulphide	S	S	S	M
Nitrobenzene	M	S	S	O
KETONES				
Acetone	O	S	S	O
DETERGENTS & OTHER CLEANING PRODUCTS				
Calgonite (1%)	O	O	O	O
Chlorox (1%)	O	O	O	O
Chlorox (Conc.)	O	O	O	O
Joy (1%)	O	O	O	O
Joy (Conc.)	O	O	O	O
Lestoil (1%)	O	O	O	O
Lux Flakes (1%)	O	O	O	O
Rinse Dry (1%)	O	O	O	O
Rinse Dry (Conc.)	O	O	O	O
Tide (1%)	O	O	O	O
NATURAL FATS & OILS				
Butter	M	S	O	O
Caster Oil	O	S	O	O
Cottonseed Oil	O	S	O	O
Lard	M	S	O	O
Oleomargarine	M	S	O	O
Olive Oil	O	S	O	O
White Mineral Oil	M	S	O	O
OILS & FUELS				
A.S.T.M. No. 1 Oil	S	S	S	O
A.S.T.M. No. 2 Oil	S	S	S	O
A.S.T.M. No. 3 Oil	S	S	S	O
A.S.T.M. Fuel A	S	S	S	O
A.S.T.M. Fuel B	S	S	S	O
A.S.T.M. Fuel C	S	S	S	O
Heating Fuel Oil	S	S	S	O
Jet Aircraft Engine Oil	S	S	S	O
HYDRAULIC FLUIDS				
Oronite 8200	S	S	S	M
Pydraul F 9	S	S	S	M
Pydraul 60	S	S	S	M
Skydrol	S	S	S	M
Skydrol 500	S	S	S	M
MISCELLANEOUS				
Gelatine (sat. sol'n)	O	O	O	O
Glucose (sat. sol'n)	O	O	O	O
Tincture of Iodine	M	M	S	O
Prestone antifreeze	O	O	O	O
Dowgard antifreeze	O	O	O	O

The information and recommendations contained in this bulletin are based on data which we believe are reliable but all such information and recommendations are given without guarantee or warranty

PACESETTERS IN FLEXIBLE LININGS.

Gundle

matrecon, inc.

RESEARCH · CONSULTING · TESTING · NON-METALLIC MATERIALS

Oakland, CA 94623

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Oakland, CA 94608

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#2

M82-74

cc – Matrecon
UNC Eng file
Peterson Original. – Place
Seam Samp
in UNC
Eng. File

March 12, 1982

Dr. Richard K. Schmidt, President
Gundle Lining Systems, Inc.
1340 East Rickey Road
Houston, TX 77073

Dear Rich:

Re: Results of Compatibility Testing of 30 Mil Gundline in United Nuclear Waste Liquid For Four Months at 23 and 50°C

We have completed the four months of compatibility testing in the United Nuclear Waste Liquid of the 30 mil Gundline samples, labelled A and B, that we received from David Small on September 24, 1981. David requested that we test these two samples and report the results separately.

The test results for the unexposed materials and the materials after immersion for one, two, and four months are presented in Tables 1-5:

Table 1 - 30 Mil Gundline Immersed in United Nuclear Waste for Various Exposure Periods - Sample A.

Table 2 - 30 Mil Gundline Immersed in United Nuclear Waste for Various Exposure Periods, Percent Retentions - Sample A.

Table 3 - 30 Mil Gundline Immersed in United Nuclear Waste for Various Exposure Periods - Sample B.

Table 4 - 30 Mill Gundline Immersed in United Nuclear Waste for Various Exposure Periods, Percent Retentions - Sample B.

Table 5 - Locus of Failure in 30 Mil Gundline Seams Tested in Peel.

Details of Testing

Seven-inch samples of Sheetings A and B were cut for immersion testing. Two holes were punched into the transverse edge from which to hang the samples in the machine direction. Seven-inch square samples bisected by a seam were also cut and punched on the edge parallel to the seam.

The sheeting samples were weighed to 0.01 gram. The length or machine direction and width, transverse direction, were measured 2 cm from each end and through the center; these three values were averaged to 0.05 cm. The gage was measured in all four corners and averaged to 0.1 mils. Loops of Teflon cord were tied through the holes in the samples and polyethylene identification tags attached.

The United Nuclear Waste liquid was stirred and poured into 8" x 8" Nalgene tanks. These tanks are fitted with removable glass rods across the top. The samples were hung by Teflon cord from these glass rods. One tank was left at room temperature and the other put into a 50°C oven.

After each exposure period, test samples were removed. They were rinsed in deionized water and stored in zip-lock bags between tests. The samples from the 50°C oven were allowed to condition for eight hours at room temperature in the storage bags. All testing was performed at room temperature before they were allowed to dry out.

Samples were blotted and weight and dimensions measured following the same procedure as for the unexposed samples. Physical testing was then conducted, on blotted specimens. Following the layout for physical testing presented in Figure 1, the tests conducted were:

Test	Method	Details
Tensile properties	ASTM D638	At 2 ipm, Goodyear dumbbells
Tear strength	ASTM D1004	At 2 ipm, Die C
Modulus of elasticity	ASTM D882	At 0.2 ipm, 0.5" x 6" strips
Puncture resistance	FTMS 101B, Method 2065	
Seam strength	ASTM D413	At 2 ipm, Die I Dumbbell
Hardness	ASTM D2240	If Duro A >80, Duro D data collected.
Volatiles (as received	Matrecon Test Method 1	Tests specimens are dried gradually to avoid bubbling. Heat at 50°C to stable weight, 70°C to stable weight, 105°C for 2 hours and weigh.
Extractables (dry basis)	Matrecon Test Method 2	Air dry samples in moving air for 16 hours, heat at 105°C for 2 h and weigh sample, extract sample with MEK for 16 h, evaporate solvent and weigh extract at 70°C for 2 h and weigh extract.

Except as noted below, the physical properties of both samples were similar and remained essentially unaffected by the immersion in the United Nuclear Waste at both temperatures. There was some loss in elongation in the tensile test and in the puncture test, particularly at 50°C immersions. The stress and puncture, however, remained essentially the same during the immersion.

Seam strengths of Sample A, measured in shear, at both temperatures were about the same as those of the unexposed seams. Seam strengths of Sample B at both temperatures continued to be greater than those of the unexposed seams. While average peel strength values generally retained their exposed levels, failures in the seam at the interface have again occurred in three of the four immersions. (Table 5). Although no peel seam failure occurred in Sample B seams at 23°C, one peel test specimen had significant seam separation before a final break at the seam edge.

For your observation, I enclose three tested seam specimens which had been immersed in the United Nuclear Waste and which failed at the interface between two layers of the Gundline which had been bonded. Of the total number of 56 specimens that were tested, 11 specimens failed in this manner and seven failed partially. However, if only the immersed specimens were considered, the percentage of failures would be even higher. It is to be noted that the magnitude of the peel, even in the case of those specimens that failed at the interface, was essentially equal to the specimens that failed either at the seam edge or in the substrate.

If you have any questions regarding these results, please contact me.

Sincerely

Henry E. Haxo, Jr.
President

vlm

encls. 5 Tables
1 Figure

cc: Mr. Cliff Gundle
Dr. Rod Tinkler

TABLE 1. 30 MIL GUNDLINE IMMERSED IN UNITED NUCLEAR WASTE FOR VARIOUS EXPOSURE PERIODS
Sample A

	Direction of test	Unexposed	Exposure at 23°C, months			Exposure at 50°C, months		
			1	2	4	1	2	4
Analytical properties:								
Weight, % change		...	-0.3	0	0.09	2.9	0.2	4.5
Volatiles, %		...	0.31	0.33	0.33	0.41	0.44	0.40
Extractables, %		1.28	1.09	1.32	1.37	1.85	1.67	1.74
Physical properties:								
Average measured thickness, mils		...	32.8	30.4	31.9	32.8	31.8	31.5
Tensile at yield, psi	Machine	1870	1890	1850	1800	1720	1660	1775
	Transverse	1915	2030	1945	1925	1810	1865	1820
Elongation at yield, %	Machine	17	23	18	25	22	25	20
	Transverse	17	22	18	22	20	25	18
Tensile at break, psi	Machine	3830	4085	3770	3810	3705	3630	3650
	Transverse	3755	3730	3880	3920	3560	3880	3595
Elongation at break, %	Machine	905	935	900	950	960	950	915
	Transverse	910	915	950	1010	960	985	940
Tensile set, %	Machine	770	800	760	795	815	805	765
	Transverse	770	785	825	860	800	830	780
S-100, psi	Machine	1535	1570	1510	1560	1420	1380	1510
	Transverse	1505	1565	1500	1525	1395	1450	1460
S-200, psi	Machine	1580	1615	1545	1555	1435	1415	1510
	Transverse	1545	1620	1505	1535	1440	1560	1480
Modulus of elasticity, psi	Machine	55,100	47,000	46,500	54,800	48,500	51,600	51,100
	Transverse	58,100	57,500	63,700	59,300	56,200	66,400	55,000
Tear strength, ppi	Machine	730	745	705	725	720	680	685
	Transverse	725	685	650	700	725	645	710
Puncture resistance								
Thickness, mils		32.6	34.0	30.0	32.5	37.0	34.0	34.0
Stress, lbs		43.4	47.6	39.8	43.3	43.5	46.7	42.7
Elongation, in		0.92	0.86	0.46	0.50	0.78	0.80	0.44
Seam strength, ppi								
Maximum peel		72.3	70.6	74.5	66.2	63.2	63.7	67.8
Maximum shear		77.3	82.8	78.3	75.4	74.4	75.4	74.8
Hardness, Duro D:								
Instant reading		500	520	510	530	520	510	510
5-second reading		480	480	470	480	470	470	460

Matrecon, Inc.
MA2-74 <[illegible]>
March 9, 1982

Table 2

30 MIL GUNDLINE IMMERSED IN UNITED NUCLEAR WASTE FOR VARIOUS EXPOSURE PERIODS, PERCENT RETENTIONS

Sample A

	Direction of test	Exposure at 23°C, months			Exposure at 50°C, months		
		1	2	4	1	2	4
Analytical properties							
Weight, % change		-0.3	0	0.09	2.9	0.2	4.5
Physical properties							
Tensile at yield, % retention	Machine	101	99	96	92	89	95
	Transverse	106	102	101	95	97	95
Elongation at yield, % retention	Machine	135	106	147	129	147	118
	Transverse	129	106	128	118	147	108
Tensile at break, % retention	Machine	107	98	99	97	95	95
	Transverse	99	103	104	95	103	96
Elongation at break, % retention	Machine	103	99	105	106	105	101
	Transverse	101	104	111	105	108	104
Tensile set, % retention	Machine	104	98	103	106	104	99
	Transverse	101	107	111	104	108	101
S-100, % retention	Machine	102	99	102	93	90	98
	Transverse	104	100	101	93	96	97
S-200, % retention	Machine	102	97	98	90	89	95
	Transverse	105	97	99	93	101	96
Modulus of elasticity, % retention	Machine	85	84	99	88	94	93
	Transverse	99	110	102	97	114	95
Tear strength, % retention	Machine	102	96	99	99	93	94
	Transverse	94	89	96	99	89	98
Puncture resistance, % retention							
Thickness		104	92	100	113	104	104
Stress		110	92	100	100	108	98
Elongation		93	50	54	85	87	48
Seam strength, % retention							
Maximum peel		98	103	91	87	88	94
Maximum shear		107	101	98	96	98	97
Hardness, change in points							
Instant reading		+20	+10	+30	+20	+10	+10
5-second reading		+20	+10	+20	+10	+10	00

Matrecon, Inc.
M82-74 <808>
March 9, 1982

TABLE 3. 30 MIL GUNDLINE IMMERSED IN UNITED NUCLEAR WASTE FOR VARIOUS EXPOSURE PERIODS
Sample B

	Direction of test	Unexposed	Exposure at 23°C, months 1	2	4	Exposure at 50°C, months 1	2	4
Analytical properties:								
Weight, % change		0	0	-0.08	0.08	1.9	3.0	2.3
Volatiles, %		...	0.31	0.36	0.39	0.39	0.44	0.39
Extractables, %		1.48	1.75	1.12	1.69	1.72	1.31	1.65
Physical properties:								
Average measured thickness, mils		...	32.8	34.6	34.2	33.1	30.7	33.3
Tensile at yield, psi	Machine	1875	1810	1900	1835	1745	1660	1910
	Transverse	1945	1870	1965	1920	1845	1765	1950
Elongation at yield, %	Machine	20	22	25	35	22	25	20
	Transverse	20	20	23	28	20	25	20
Tensile at break, psi	Machine	3980	3915	3930	3751	3740	3510	3690
	Transverse	3940	3865	4015	3575	3215	3450	3720
Elongation at break, %	Machine	935	965	940	910	960	950	915
	Transverse	940	960	960	950	885	940	915
Tensile set, %	Machine	815	805	805	775	750	815	760
	Transverse	785	810	795	810	735	825	805
S-100, psi	Machine	1515	1495	1525	1560	1420	1355	1575
	Transverse	1510	1460	1505	1525	1400	1365	1540
S-200, psi	Machine	1565	1530	1555	1560	1460	1395	1580
	Transverse	1575	1520	1565	1530	1440	1390	1560
Modulus of elasticity, psi	Machine	58,600	53,700	60,000	52,600	48,300	59,400	55,300
	Transverse	65,400	57,000	65,700	57,200	53,100	67,100	58,000
Tear strength, ppi	Machine	750	730	760	725	705	680	725
	Transverse	745	720	745	700	705	665	710
Puncture resistance								
Thickness, mils		34.5	33.0	32.5	33.0	36.0	36.0	34.0
Stress, lbs		45.6	47.7	44.0	45.8	48.7	47.3	41.2
Elongation, in		0.66	0.96	0.56	0.54	0.94	0.88	0.28
Seam strength, ppi								
Maximum peel		68.8	63.3	62.3	60.2	54.8	50.8	70.6
Maximum shear		63.0	66.4	84.2	69.4	66.5	73.7	78.4
Hardness, Duro D:								
Instant reading		500	530	490	530	530	500	530
5-second reading		460	480	450	470	480	460	470

TABLE 4
30 MIL GUNDLINE IMMERSED IN UNITED NUCLEAR WASTE FOR VARIOUS EXPOSURE PERIODS, PERCENT RETENTIONS
Sample B

	Direction of test	Exposure at 23°C, months			Exposure at 50°C, months		
		1	2	4	1	2	4
Analytical properties							
Weight, % change		0	-0.09	0.08	1.9	3.0	2.3
Physical properties							
Tensile at yield, % retention	Machine	97	101	98	93	89	96
	Transverse	96	101	99	95	91	100
Elongation at yield, % retention	Machine	110	125	175	110	125	100
	Transverse	100	115	140	100	125	100
Tensile at break, % retention	Machine	98	99	94	94	88	93
	Transverse	98	102	91	82	88	94
Elongation at break, % retention	Machine	103	101	97	102	102	98
	Transverse	102	102	101	94	100	97
Tensile set, % retention	Machine	99	98	95	92	100	93
	Transverse	103	101	103	93	105	103
S-100, % retention	Machine	99	101	103	94	89	104
	Transverse	97	99	101	93	90	102
S-200, % retention	Machine	98	100	100	93	89	101
	Transverse	96	99	97	91	88	99
Modulus of elasticity, % retention	Machine	92	102	90	82	101	94
	Transverse	87	100	88	81	103	89
Tear strength, % retention	Machine	98	101	96	94	91	97
	Transverse	96	100	93	94	89	95
Puncture resistance, % retention							
Thickness		96	94	96	104	104	99
Stress		105	96	100	107	104	90
Elongation		145	85	82	142	103	42
Seam strength, % retention							
Maximum peel		92	91	88	80	74	103
Maximum shear		105	134	110	106	117	124
Hardness, change in points							
Instant reading		+30	-10	+30	+30	00	+30
5-second reading		+20	-10	+10	+20	00	+10

Table 5. LOCUS OF FAILURE IN 30 MIL GUNDLINE SEAMS TESTED IN PEEL

	Exposure, months	Temperature, °C	Number of specimens	Locus of failure[a] SE	BRK	LS-SE	LS	NB	Average peel strength, ppi
Sample A	Unexposed	-	5	3	-	-	-	2	72.3
	1	23	4	2	-	1	1	-	70.6
	2	23	4	3	-	-	-	1	74.5
	4	23	4	1	-	-	2[b]	1	66.2
	1	50	4	1	-	3	-	-	63.2
	2	50	4	2	-	-	1	1	63.7
	4	50	4	1	-	1	2	-	67.8
Sample B	Unexposed	-	4	3	1	-	-	-	68.8
	1	23	4	4	-	-	-	-	63.3
	2	23	4	4	-	-	-	-	62.4
	4	23	4	3	-	1[c]	-	-	60.2
	1	50	4	3	-	-	1	-	54.8
	2	50	3	-	-	-	3	-	50.8
	4	50	4	2	-	1	1[d]	-	70.6
Total number of specimens			50 6	32	1	7	11	5	

[a] Locus of failure code:
SE = Samples broke at seam edge.
BRK = Samples broke in liner away from seam edge (not in clamps).
LS-SE = Seam started to fail; final break at seam edge.
LS = Seam failed.
NB = No break, samples pulled to full elongation without breaking.

[b] Sample accompanies report, labeled #13, p 3.

[c] Sample accompanies report, labeled #23, p 4.

[d] Sample accompanies report, labeled #27, p 4.

Matrecon, Inc.
MU2-74
March 9, 1982

Gundle Lining Systems Inc

LABORATORY REPORT #210

MARCH 23, 1983

SUBJECT

Chemical Compatibility of GUNDLINE® HD 40 and 60 mil to Kerosene.

SUMMARY

A small decrease in tensile properties was observed after 30 days immersion.

TEST METHOD

GUNDLINE® HD 40 and 60 mil material was placed in kerosene at room temperature (23°C) for immersion testing. Samples were removed from the kerosene after 7 and 30 days. ASTM D638 Type IV dumb-bells were used for tensile testing. A 1" x 4" strip was used for weight and dimensional change. These strips were removed from the solution, weighed, the average thickness was recorded, and then replaced in the solution until the next immersion time interval. Tensile properties were also performed on a control of the 40 and 60 HD mil material.

TEST RESULTS

TENSILE	MD Yield PSI	MD Break PSI	MD % Elong @ Break	TD Yield PSI	TD Break PSI	TD % Elong @ Break
40 mil						
Control	2775	5023	795	2987	5240	890
7 Day	2505	4439	767	2549	4719	813
	(9.7)	(11.6)	(3.5)	(14.7)	(9.9)	(8.7)
30 Day	2450	4436	777	2603	4911	837
	(11.7)	(11.7)	(2.3)	(12.9)	(6.13)	(5.6)
60 mil						
Control	2767	5219	945	2881	5008	980
7 Day	2518	4526	787	2605	4941	870
	(8.9)	(13.3)	(16.7)	(9.6)	(1.3)	(11.0)
30 Day	2501	4684	833	2580	4979	827
	(9.6)	(10.0)	(12.0)	(10.0)	(0.6)	(16.0)

Note: Numbers in () are % decrease in values.

WEIGHT AND DIMENSIONAL CHANGE

	Initial	7 Day (%)	30 Day (%)
40 mil			
Weight (grams) (1)	3.5386	3.7824 (6.9)	3.7901 (7.1)
Thickness (mils)	44	44	44
Weight (grams) (2)	3.4240	3.6587 (6.9)	3.6708 (7.21)
Thickness (mils)	43	44	44

WEIGHT AND DIMENSIONAL CHANGE

60 mil	Initial	7 Day (%)	30 Day (%)
Weight (grams) (1)	6.2954	6.5152 (3.5)	6.7259 (6.8)
Thickness (mils)	71	71	72
Weight (grams) (2)	6.3888	6.6140 (3.52)	6.8194 (6.7)
Thickness (mils)	70	71	71

Note: Numbers in () are % increase in weight.

CONCLUSION

A small decrease in tensile properties was observed after the 7 and 30 days immersion; however, the tensile strength and elongation at break did not change significantly between the 7 and 30 day intervals. The tensile properties of high density material may vary as much as 10% from one sample to another. With this kept in mind, the decrease seen after immersion could be partly due to the characteristics of HDPE.

Gloria Garber

Gloria Garber, Lab Technician

GG/bj

Gundle Lining Systems Ltd.

Gundle

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North Vancouver,
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04-352815
Tel. (604) 980-8337

08/056

December 5, 1983

Mr. Dick Cave
KILBORN LIMITED
2200 Lakeshore Blvd. West
TORONTO, Ontario
M8V 1A4

Dear Dick:

You will recall the conversation we had with respect to permeability on the Denison Potacan project. I am continuing to review our records and reports that have been prepared on this subject and on my recent visit to Houston I took a copy of a handwritten report which was prepared by Woodward Clyde on September 16th with respect to the subject. Woodward Clyde did a calculation from water vapor transmission data and as you can see from the report, the permeability thus calculated is 2.7 x 10 -13 cm/sec. This is in the same magnitude as the permeability which we reported to Dave Clark recently.

In addition to the above, you are probably aware that Matrecon has done a number of studies for the E.P.A., some of which have been done in sodium chloride aqueous solutions. The conclusions from these reports by both the E.P.A. and the U.S. Water & Power Services is that for all intense purposes, the membrane may be considered to be impermeable. Matrecon ran tests for Gundle in 1981 with 5% sodium chloride aqueous solution and in an exposure period of 8 weeks there was no identifiable loss of fluid. In summary, the information which is available, both internally and from E.P.A., Matrecon and Water Research Centre indicates that a magnitude in the range of 10 -13 or 10 -14 is an appropriate theoretical figure but for all intense purposes the material may be considered impermeable. As everyone has identified, and as you have, the potential for mechanical damage caused by vandalism

84

...... 2

animals or improper installation is a much more significant consideration.

We hope that this additional information will be of some value to you. We intend to correspond with you in the next few days with regard to the thickness specifications, however, with the description of the types of base preparation which we received from Dave Clark and the head, we believe that thickness should be in the magnitude of 1.5mm or greater.

Yours very truly,

GUNDLE LINING SYSTEMS LTD.

G.W. Salberg, P. Eng.
Managing Director

GWS/dlj
Encls.

c.c. Mr. Dave Clark
Mr. R.P. Lewington

1. 9

Gundle Lining Systems Inc

Gundle™

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Houston, Texas 77073
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GUNDLE HOU
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STANDARD SPECIFICATIONS FOR GUNDLINE® HDPE (HD) LINING MATERIAL

1.00 SCOPE

These specifications describe Gundle Lining Systems, ~~Inc~~ "GUNDLINE® Lining Membranes. The supply and installation of these materials shall be in strict accordance with the Engineer's specifications and engineering drawings and be subject to the terms and conditions of the contract.

2.00 MANUFACTURER'S EXPERIENCE

2.01 The manufacturer of the lining material described hereunder shall have previously demonstrated his ability to produce this membrane by having successfully manufactured a minimum of ten million square feet of similar liner material for hydraulic lining installations.

2.02 Pre-Bid Submittals

36

In order to qualify as an approved material lining manufacturer, the manufacturer shall submit lining material samples and minimum specifications to the Engineer 60 days prior to the bid closing date for approval. The specification sheet shall give full details of minimum physical properties and test methods used, site seaming methods, and a certificate confirming compliance of the material with the minimum specifications. A list of similar projects completed in which the manufactured material has been successfully used shall be submitted to the Engineer.

The lining manufacturer shall also submit a list of approved licensed installers who have been trained and who are qualified to install the manufacturer's material.

3.00 LINING MATERIAL

3.01 The membrane liner shall comprise unsupported GUNDLINE® HD material manufactured of new, first-quality products designed and manufactured specifically for the purpose of liquid containment in hydraulic structures.

3.02 The Contractor shall, at the time of bidding, submit a certification from the manufacturer of the sheeting, stating that the sheeting meets physical property requirements for the intended application.

3.03 The liner material shall be so produced as to be free of holes, blisters, undispersed raw materials, or any sign of contamination by foreign matter. Any such defect shall be repaired using the extrudate welding technique in accordance with the manufacturer's recommendations.

3.04 The lining material shall be manufactured a minimum 22.0' seamless width. Labels on the roll shall identify the thickness, length, width, and manufacturer's mark number.

3.05 The liner material shall meet the minimum specification values according to the Gundle Specification Sheet for GUNDLINE® HD.

4.00 FACTORY QUALITY CONTROL

4.01 Raw Material

All compound ingredients of the GUNDLINE® materials shall be randomly sampled on delivery to the Gundle manufacturing plant to ensure compliance with purchase specifications. Tests to be carried out shall include Density ASTM D1505.68 and Melt Index ASTM D1238-79 Procedure A, Condition P.

4.02 Manufactured Roll Goods

Samples of the production run shall be taken and tested according to ASTM D638.82 to ensure that tensile strength at yeild and break, elongation at yield and break meet the minimum specifications. A quality control certificate shall be issued with the material.

4.03 All welding material shall be of a type recommended and supplied by the manufacturer and shall be delivered in the original sealed containers - each with an indelible label bearing the brand name, manufacturer's mark number, and complete directions as to proper storage.

5.00 INSTRUCTIONS AND DRAWINGS REQUIRED AFTER CONTRACT AWARD

5.01 The manufacturer shall furnish complete written instructions for the storage, handling, installation, and seaming of the liner in compliance with this specification and the condition of his warranty.

5.02 The material supplier shall furnish complete written instructions for the repair of GUNDLINE® material.

5.03 The manufacturer or his designated representative shall furnish panel layouts as required for the liner installation. Final lagoon configuration, attachment details, and survey information needed will be furnished by the end user or his designated representative.

6.00 INSTALLATION

6.01 Area Subgrade Preparation

Surfaces to be lined shall be smooth and free of all rocks, stones, sticks, roots, sharp objects, or debris of any kind. The surface should provide a firm, unyielding foundation for the membrane with no sudden, sharp or abrupt changes or break in grade. No standing water or excessive moisture shall be

allowed. The installation contractor shall certify in writing that the surface on which the membrane is to be installed is acceptable before commencing work.

3. * ADD subgrade statement —

6.02 Soil Sterilization (If Necessary)

A local vegetation expert should determine the types of vegetation in the area and suggest a treatment to rid the site to be lined of vegetation. This may be performed by the installation contractor, and the recommendations of the vegetation expert are to be followed.

6.03 Contractor Approval

The installation contractor shall have met the manufacturer's minimum requirements to become a licensed installer of the manufacturer's product using the manufacturer's state-of-the-art equipment and welding methods. The manufacturer shall certify that the installer is licensed by Gundle.

6.04 Field Seams

Individual panels of liner material shall be laid out and overlapped by a minimum of 2 inches prior to welding. Extreme care shall be taken by the installer in the preparation of the areas to be welded. The area to be welded shall be cleaned and prepared according to the procedures laid down by the material manufacturer. All sheeting shall be welded together by means of a homogeneous overlap extrusion fusion process which provides continuous dynamic integration of the extrudate bead with the lining material. The composition of the extrudate shall be identical to the lining material.

6.05 The welding equipment used shall be capable of continuously monitoring and controlling the temperatures of the extrudate and the zone of contact where the machine is actually fusing the lining material so as to ensure changes in environmental conditions will not affect the integrity of the weld. Only welding systems which utilize the extrusion process shall be used for bonding these lining materials.

6.06 No "fish mouths" shall be allowed within the seam area. Where "fish mouths" occur, the material shall be cut, overlapped, and an overlap-extrusion weld shall be applied. All welds on completion of the work shall be tightly bonded. Any membrane area showing injury due to excessive scuffing, puncture, or distress from any cause shall be replaced or repaired with an additional piece of GUNDLINE® membrane.

7.00 FIELD SEAM TESTING/QUALITY CONTROL

7.01 The installer shall employ on-site physical non-destructive testing on all welds to ensure watertight homogeneous seams.

7.02 A quality-control technician shall inspect each seam. Any area showing a defect shall be marked and repaired in accordance with Gundle's repair procedures.

need. strength of

7.03 A test weld three (3) feet long from each welding machine shall be run each day prior to liner welding and under the same conditions as exist for the liner welding. The test weld shall be marked with date, ambient temperature, and welding machine number. Samples of weld 1/4" to 1/2" wide shall be cut from the test weld and pulled in shear and peel. Seams should be stronger than the material. The weld sample shall be kept for subsequent testing on laboratory tensometer equipment in accordance with the applicable ASTM tests. Random weld samples may be removed from the installed welded sheeting at a frequency to be agreed (eg. 1/500' of weld).

7.04 The end user company, or his designated representative, reserves the right of access for inspection of any or all phases of this installation at their expense.

8.00 WARRANTY AND GUARANTEE

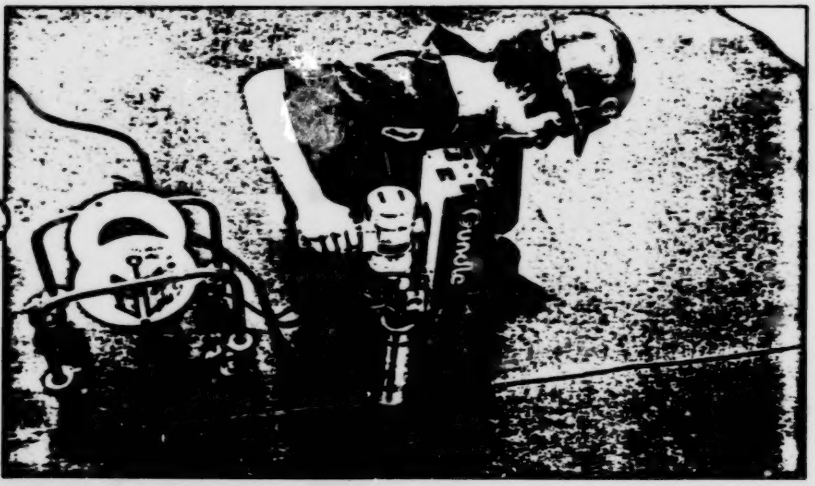
8.01 The manufacturer/installer shall provide a written warranty stating a duration of time during which the liner materials and workmanship specifically provided or performed under this project shall be free from any significant defects. Said warranty shall apply to normal use and service by the owner and specifically excludes mechanical abuse or puncture by machinery, equipment, or people, exposure of the liner to harmful chemicals or catastrophe due to earthquake, flood, or tornado. Such written warranty shall provide for the total and complete repair or replacement of the defect or defective area of lining materials upon written notification and demonstration by the owner of the specific non-conformance of the lining material or installation with the project specifications. Such defects or non-conformance shall be repaired or replaced within a reasonable period of time at no cost to the owner provided that portion of the area in question has been made available to the manufacturer/installer and that such areas have been cleared of all liquids, sludges, dirt, sand, or gravel.

* * * * *

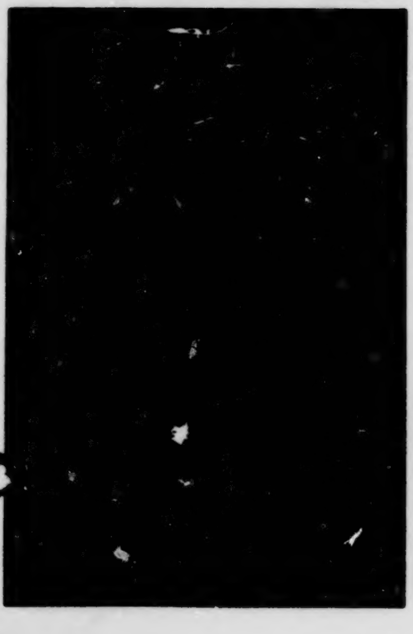
Gundle

2.6/Gu

Gundline® Flexible Membrane Lining Systems



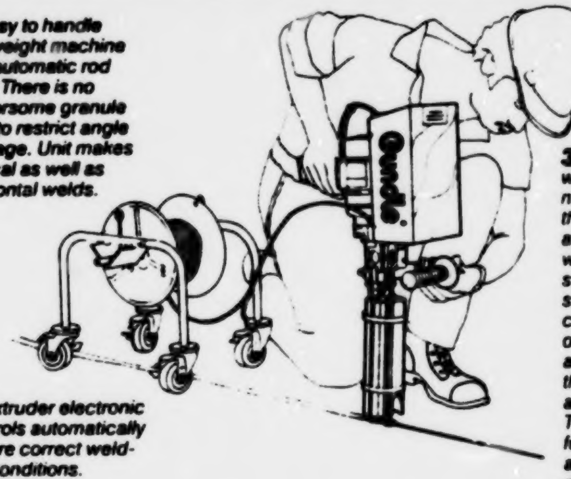
The Gundle Fusion Welding Machine quickly produces integrated welds that are strong and as durable as the sheeting itself. It works efficiently for the installation of Gundline® pond and retention liners.



Gundle Fusion Welding: the process which consistently gives you seams strong and as durable as the sheet.

Until now, the most failure-prone part of flexible membrane liners has been the seam. Various bonding methods have been used, but none could produce a seam that would withstand as much physical stress and weathering as the sheet itself. Now Gundle has the answer: Gundle Fusion Welding . . . a patented, field-applied process. Its effectiveness has been proven repeatedly in rigorous laboratory tests and in successful field applications worldwide.

For more detailed information request a copy of our Gundline® Flexible Membrane Lining Systems brochure.



1 Easy to handle lightweight machine with automatic rod feed. There is no bothersome granule feed to restrict angle of usage. Unit makes vertical as well as horizontal welds.

2 Extruder electronic controls automatically assure correct welding conditions.

3 Gundle's unique welding method dynamically integrates the sheets. It creates a fusion weld using welding rod of the same material as the sheet itself. This mechanical integration of the sheets eliminates any boundary layers that would be weak and subject to failure. The system uses no foreign solvents or adhesives which can degenerate over time.

SPECIFICATIONS

PROPERTY	TEST METHOD	GAUGE (NOMINAL)					
		20 Mil	30 Mil	40 Mil	60 Mil	80 Mil	100 Mil
Density (g/cc) (Minimum)	ASTM D1505	0.94	0.94	0.94	0.94	0.94	0.94
Minimum Tensile Properties (Each direction)	ASTM D638 Type IV Dumb-bell at 2 ipm.						
1. Tensile Strength at Break (Pounds/inch width)		80	120	160	240	320	400
2. Tensile Strength at Yield (Pounds/inch width)		50	70	95	140	190	240
3. Elongation at Break (Percent)		700	700	700	700	700	700
4. Elongation at Yield (Percent)		13	13	13	13	13	13
5. Modulus of Elasticity (Pounds/square inch)	ASTM D882	110,000	110,000	110,000	110,000	110,000	110,000
Tear Resistance Initiation (Pounds minimum)	ASTM D1004 Die C	15	22	30	45	60	75
Low Temperature	ASTM D746 Procedure B	−40°F	−40°F	−40°F	−40°F	−40°F	−40°F
Dimensional Stability (Each direction, percent change maximum)	ASTM D1204 212°F 1 hr.	±2	±2	±2	±2	±2	±2
Volatile Loss (Maximum %)	ASTM D1203 Method A	0.1	0.1	0.1	0.1	0.1	0.1
Environmental Stress Crack (Minimum hours)	ASTM D1693	750	750	750	750	750	750

Gundline® High Density Polyethylene: the geomembrane designed specifically for exposed conditions.

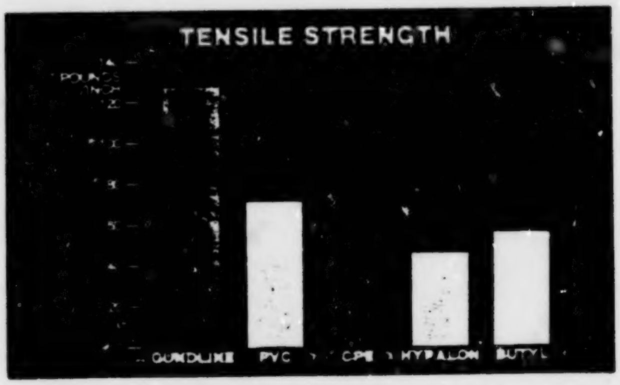
Gundle Fusion Welding, an extrusion-type process, is the *only* process in which complete integration occurs between the molten weld bead and the surfaces of two sheets—thus the name "Fusion Welding™." This is critically important because anything less than complete mixing—true homogeneous bonding—fails to give a durable, strong seam.

No integration of extrudate with sheet.

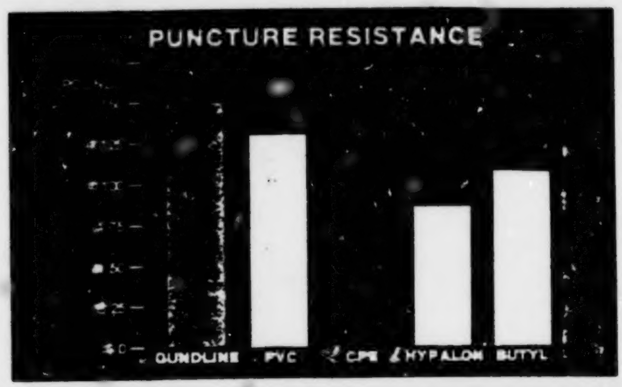
Fusion welding forms a truly homogeneous bond.

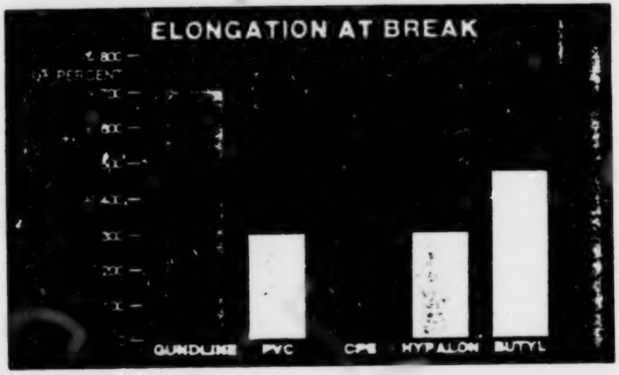
Even the best HDPE (high density polyethylene) seaming system can be no better than the quality of the sheets it is intended to join. A recent 30-mil comparison test (figure 1) demonstrated that GUNDLINE HDPE membranes provide 44% greater breaking strength than competitive reinforced materials; 77% greater than unreinforced PVC.

GUNDLINE*-HDPE is high density polyethylene stabilized to provide outdoor durability. It is extremely resistant to chemicals and oils, and highly puncture resistant.



The GUNDLINE membranes' puncture resistance (figure 2) and maximum elongation (figure 3) proved to be significantly greater also. Their weatherability and hydrocarbon resistance are excellent. Complete test results are available from Gundle.





GUNDLINE sheeting is available in an exceptionally broad range of thicknesses: 20 to 100 mils (0.5 mm to 2.5 mm). It is manufactured in seamless widths of 22.5 ft., (6.75 m) reducing the number of total seams required by as much as 75%.

Chemical	HDPE	CPE	CSPE	PVC
Aliphatic Hydrocarbons	X			
Aromatic Hydrocarbons	X	•		
Crude Petroleum Products	X			
Acids	X	X	X	X
Bases	X	X	X	X
Heavy Metals	X	X	X	X
Salts	X	X	X	X

X = GENERALLY GOOD RESISTANCE

Resistance to oil and hydrocarbons is usually a prime consideration. Compare GUNDLINE*-HDPE with three other widely used materials and you'll see the advantage you gain across the board in chemical resistance. For more detailed information request a copy of the Gundle Chemical Resistance Chart.

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*Registered trademark of E.I. Dupont

Gundle Lining Systems, Inc., 1340 East Richey Road
Houston, Texas 77073 USA Phone (713) 443-8564
USA Telex – 792804 GUNDLE HOU
International Telex – 6868205 GUNDLE HOU

In Canada contact: Gundle Lining Systems, Ltd.
301-255 1st Street West, North Vancouver, BC V7M 3G8
Phone (604) 980-8337 Telex-04-352815

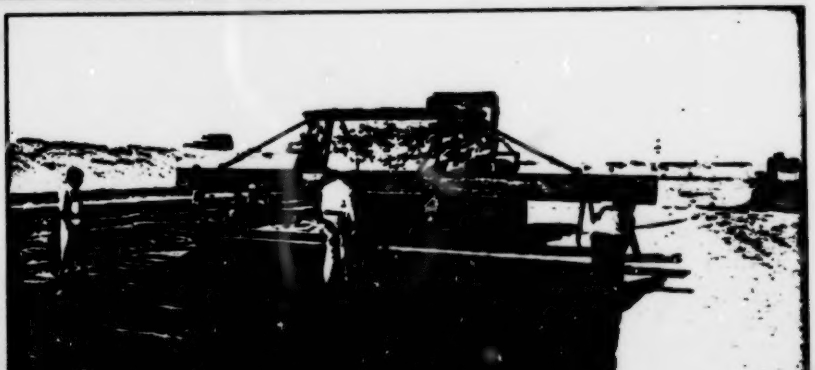
Gundle

The advanced technology lining system.

Gundline flexible membrane linings are manufactured in the most modern plant in the industry.

1. Gundle's modern manufacturing facility is capable of producing over 85,000,000 square feet annually of lining products. 2. Large western utility used 40 mil GUNDLINE for brine pond application. Daytime temperatures in this exposed application approached 110-120°F, (43-49°C). 3. Gundle has one of the most modern laboratories in the industry capable of performing a variety of physical and chemical resistance tests. The lab is available for customer use. 4. Gundle offers the widest seamless HDPE sheet in the industry. Rolls are 22.5 feet (6.75 m) wide and vary in length depending on thickness. Standard roll weight is 2800 lb (1270 kg). Rolls are easy to handle in the field.

Gundle
Gundle Lining Systems Inc



APPENDIX D-2-2

DUNLOP CONSTRUCTION PRODUCTS INC.

DUNLOP
CONSTRUCTION PRODUCTS INC.

April 12, 1984

Mr. Frederick W. Firlotte, P. Eng.
Associate
Golder Associates
500 Nottinghill Road
LONDON, Ontario
N6K 3P1

Dear Rick:

Dunlop Construction Products, Inc. manufacture membranes of EPDM, CPE, Neoprene, Butyl and Hypalon. We started producing material in our new plant, located in Huron Park, Ontario, in June/83. There is some confusion in the market place about who manufactures Dunlop membranes - for good reason. For years, membrane has been produced by Dunline Division of Dunlop Industrial Limited in their plant, also in Huron Park. Both companies report to Dunlop Holdings plc, U.K., though Dunlop Construction Products, Inc. has a major Canadian shareholder, Bitumar, Dunline is wholly owned by Dunlop Holdings plc, U.K.

As a representative of Dunlop Construction Products, Inc., I am pleased to provide any information that I can on the products we make and products that will be part of our standard range.

The enclosed information is fairly general - for more specific information, please feel free to contact me at any time. I have followed your format reasonably closely, thus the number will correspond to the numbers on your questionaire.

Very truly yours,
DUNLOP CONSTRUCTION PRODUCTS, INC.

Robert Rayfield
Manager
Geomembranes & Containment

RR/jp
Encl.

2055 Flavelle Blvd., Mississauga, Ont., Canada, L5K 1Z8, Phone (416) 823-8200, Telex 06-982445

1) PHYSICAL PROPERTIES *

		EPDM Unreinf.	EPDM Reinf.	CPE *** Unreinf.	CPE *** Reinf.	BUTYL*** Unreinf.	NEOPRENE*** Unreinf.	HYPALON Unreinf.	HYPALON Reinf.
i)	Tensile psi Grab Lbs/Inch	1400 --	1400 --	1700 --	-- 165	1400 --	1600 --	1400 120	-- 165
ii)	Puncture Lbs.	--	100	--	100	--	--	--	100
iii)	Tear Resistance Tongue **	poor	good	poor	good	poor	good	poor	good
iv)	Abrasion Resistance **	excellent	excellent	good	good	good	excellent	good	good
v)	Dimensional Stability **	excellent	excellent	poor	excellent	excellent	excellent	poor	excellent
vi)	Flexibility - °C	-55	-55	-50	-50	-55	-40	-45	-45
vii)	Creep Resistance **	excellent	excellent	poor	excellent	excellent	excellent	poor	excellent
viii)	Permiability Perm Mil	2.2	2.2	0.2	0.2	0	3	0.2	0.2

* All these products are compounded and properties can vary considerably between products made by different companies

** Qualitive

*** Estimates from preproduction materials

2) CHEMICAL COMPATIBILITY

		EPDM	CPE	BUTYL	NEOPRENE	HYPALON
i)	Uranium Tailings	no data but should be excellent	excellent	no data but should be excellent	no data but should be excellent	excellent
ii)	Oxidizing Acid (C-D) *	poor to fair	poor-good	poor-fair	poor-fair	poor-good
iii)	Mild Acid Organic Acids (C-D) *	excellent fair-exc.	excellent excellent	good fair-good	excellent poor-exc.	excellent good-exc.
iv)	Base (C-D) *	exc.-exc.	exc.-exc.	fair-good	good-exc.	exc.-exc.
v)	General	--	--	--	--	--
vi)	Hydrocarbons Aromatic Non-Aromatic	poor poor	poor good	poor poor	poor good	poor good
vii)	Volatility (Volitiles?)	none	none	none	none	none
viii)	Bacterial Resistance **	excellent	excellent	good	poor-good	excllent

* Concentrated-Diluted

** All products can be made excellent through proper compounding

3) PERFORMANCE CHARACTERISTICS

		EPDM	CPE	BUTYL	NEOPRENE	HYPALON
i)	Ozone Resistance	excellent	excellent	good	good	excellent
ii)	UV Resistance	excellent	excellent	--	--	excellent
iii)	Low Temperature	excellent	excellent	excellent	very good	excellent
iv)	High Temperature °C	150	120+	130	110	90?
v)	Potential for Cracking	very low	low	low	low	very low

4) INSTALLATION

General:

a) Site preparation should be according to standard practice for all membranes.
b) Field seams can only be made on dry membrane.
c) Seams can be checked with a 50 p.s.i. air blast
d) Reinforced membranes are more resistant to equipment damage.
e) Slope maximum is generally accepted to be 3:1. With proper design, membranes can be used vertically.

EPDM

Field seams are made by either tape or adhesive. The tape seam is faster to make and more secure. Literature and samples are enclosed.

CPE

Heat welding should only be done in plant or on a smooth substrate - as found on some roofing applications. For lining applications, multiple 5' widths are factory heat seamed to form sheets up to 10,000 sq. ft. These sheets are solvent welded or adhesive bonded on site. If reinforcement is exposed, a cap strip is recommended.

Butyl and Neoprene

Adhesive bonded in field. Temperatures above 10°C are recommended.

Hypalon

Hypalon is factory heat welded into large sheets. The large sheets are solvent welded in the field. Generally a solvent with 10% Hypalon is used. Multiple layers of this solvent can be used to cap exposed scrim. Hypalon crosslinks with age which makes seaming much more difficult on aged sheets.

5) TESTING

i) Q.C. tests on finished product are done by Dunlop Research Centre, Sheridan Park, Mississauga, Ontario. Dunlop Research Centre is likely the best rubber research facility in Canada. (Others in Canada with a great deal of expertise are: Polysar, Sarnia; Uniroyal, Elmira; Goodyear, Toronto and NRC, Ottawa.) With the exception of atomic radiation tests, any conceivably useful test can be performed on rubber membrane at Dunlop. A full range of physical and chemical tests are done regularly for Dunlop Construction Products, Inc. Dunlop Research also does effluent analysis, accelerated ageing tests, etc.

ii) Routine Quality Control

Materials

a) all materials must be approved
b) rheometric testing each mix
c) mooney every 5th mix
d) full physicals every 10th mix
e) dispersion check every mix on thermoplastics

Calendar

a) guage
b) width
c) profile
d) each roll marked # and date for physical testing at lab
e) visual - sheet from the calendar shines. Any slight imperfection is prominent. Imperfect material is removed from the calendar.

Fabrication

a) visuals
b) hardness
c) thickness
d) 12" x 12" sample removed for physical testing at lab
e) squareness
f) light table for pinholes

iii) Seams can be tested with air gun

iv) Testing for the compatibility of Hypalon in uranium tailings applications were done by Dunlop Research for Golden Associates, Toronto.

v) Dupont has a great deal of information on Hypalon in radiation, as we discussed.

6) COMPANY INFORMATION

i) Services Offered

a) membrane
    EPDM
    BUTYL
    CPE
    Neoprene
    Hypulon
b) Full range of seaming systems for above
c) Adhesives for above
d) Fixation hardware
e) Material recommendations
f) Design recommendations
g) Effluent analysis
h) Compatibility analysis

ii) Largest Sheets

CPE and Hypalon:
-from calendar 62" x 500'
-fabricated approximately 9,000 sq. ft.

Neoprene, Butyl and EPDM:
-standard 20' x 150'
-maximum 20' x 300'

iii) Plant in Huron Park, Ontario

iv) Typical roofing warranty is 15 years. Each liner application will be considered seperately.

7) PREVIOUS EXPERIENCE

Dunlop Construction Products, Inc. has done only one small job. However, Dunline has done hundreds of lining jobs with Hypalon. Those in the mining industry are listed below. For more information please contact the user or Dunline.

Agnew Lake Mines Ltd Espanola, Ont.	Tailings Dam
Aluminum Co., Shawinigan, Quebec	Cooling Pond
Canadian Rock Salt Co. Ltd., Pugwash, N.S.	Brine Holding Pond
Denison Mines Ltd., Elliot Lake, Ont.	Dam facings for Containment of Tailings from Uranium Processing
Dome Mines Ltd., South Porcupine, Ont.	Mine Dewatering Pond
Falconbridge Nickel Mines, Ontario	Tailings Dam
International Nickel, Whitefish, Ont.	Dyke Sealer for Mine Water Pond
Inter-Prov. Steel, Regina	No. 1 and 2 Mill Tailings Settling Ponds
Iron Ore of Canada Ltd, Schefferville, P.Q.	Waste Water Diversion
Quebec Cartier Mining Co, Mount Wright, P.Q.	Membrane for Three 250' dia. thickness
Rio Algom Mines Ltd., Elliott Lake, Ont.	Loose Membrane Liners for two Wood Stave Tanks
Rio Algom Mines, Research Div.	Tailings Test Cells
Rio Algom Mines	Dam facing for mine tailing effluent containment

Rio Algom Mines, Panel Mine	Tailings dams
Sidbec/Quebec Cartier, Quebec	Tailings dam
The Steel Co. of Can., Welland, Ont.	Mill Scale Settling Pit
Texas Gulf Sulphur Co., Ecstall Mine, Timmins	Dam facing for Tailing Spillway

8) MONITORING

No information available

9) COSTS

	$/meter squared
Liner material	7 - 12
Shipping Elliott Lake	.15
Shipping Athabaska	.35
Installation (no cover)	1 - 2
TOTAL	8.15 - 14.35

These costs are to be considered rough estimates only. They do not include cover or allowances for extraordinary installation conditions.

Physical Properties

DUNSEAL PROPERTY TESTED	TEST METHOD	S.I. UNITS	CUSTOMARY UNITS
EPDM			
Specific Gravity	ASTM-D-297-79	1.27	1.27
Tensile before heat aging	ASTM-D-412-75	9.7 MPa	1400 psi
Tensile after 7 days @ 240°F	ASTM-D-573-78	11.0 MPa	1600 psi
Elongation before heat aging	ASTM-D-412-75	320%	320%
Elongation after 7 days @ 240°F	ASTM-D-473-78	200%	200%
Tear Resistance	ASTM-D-624-73	30 KN/m	170 lbs/in. of width
Ozone Resistance	ASTM-D-1149-78	No Degradation	No Degradation
Low Temperature brittleness	ASTM-D-746-79	Exceeds −45°C	Exceeds −50°F
Operating Temperature range		−45° to + 115°C	−50° to + 240°F
Water Vapor transmission	ASTM-E-96-72-Method BW	3.7×10^3 Metric Perm-cm	2.2 Perm-Mil
Shore Hardness	ASTM-D-2240-75	60 ± 4 Pts.	60 ± 4 Pts.

DUNSEAL PROPERTY TESTED	TEST METHOD	S.I. UNITS	CUSTOMARY UNITS
Hypalon*			
Thickness	—	1 mm overscrim 0.7 mm selvedge	0.036 inch overscrim 0.027 inch selvedge
Hardness	Shore A	85 ± 5 Pts.	85 ± 5 Pts.
Breaking Strength	ASTM D751 (GRAB)		
	Fabric	734N	165 lbs.
	Rubber	534N	120 lbs.
Elongation	ASTM D751		
	Fabric	30%	30%
	Rubber	250%	250%
Tear Strength	ASTM D751 (TONGUE)	11.5 KN/m	65 lbs./inch
Puncture Resistance	FTMS 101B – Method 2031	450N	100 lbs. min.
Ozone Resistance	ASTM D1149, 300PPHM @ 20% strain, 400 hours @ 60°C/140°F	No effect	No effect
Shrinkage	ASTM D1204	0.0%	0.0%
Cold Bend	ASTM D2136 ⅛ inch mandrel	−50°C, no cracks	−45°F, no cracks
Factory & Field Seams (Heat Weld or DUNSEAL H309 white adhesive)	ASTM D816 Method B	Exceeds that of parent material	Exceeds that of parent material

NOTE: Above results obtained for 0.036 inch 2 ply Hypalon/1 ply fabric, white product.
Fabric 12x6 (10x10) 2:1 leno, 500 warp/fil polyester. Results vary with fabric type.

DUNLOP
CONSTRUCTION PRODUCTS INC.

DUNSEAL R119 -- ELASTOGRIP

PRODUCT DATA AND SPECIFICATION SHEET

DUNSEAL R119 ELASTOGRIP has been formulated to meet or exceed the performance requirements of 37-GP-50m. March 1978, "Standard for: Asphalt, Rubberized, Hot Applied for Roofing and Waterproofing" established by the Canadian General Standards Board.

Property	Test Method	37-GP-50m Standard	R119
Flash Point	ASTM D 92	Minimum 260°C.	315°C.
Penetration	ASTM D 1191 or D 3407	at 25°C: Max 110 at 50°C: Max 200	Less than 60 Less than 100
Flow	ASTM D 1191 or D 3407	at 60°C: Max 3mm	at 50°C: 0 at 70°C: 2 mm
Toughness	NRC/DBR Method (National Research Council/Division of Building Research, Ottawa, Canada)	Min: 5.5 J	19 J
Ratio of Toughness to Peak Load	NCR/DBR Method	Min: 0.040	0.050
Water Absorption	Immersion in Water at 50°C for 4 days	Max Gain: 0.35 g	0.08 g
Low Temperature Flexibility	Membrane at -25°C for 16 hrs. bent over 6.3mm mandrel to a 90° bend	No cracking	Pass at -30°C
Crack Bridging	0 to 3 mm crack opening and closing, at 3 mm per hr., for 10 cycles at -25°C.	No cracking, splitting or loss of adhesion	Pass

3/15/84

2055 Flavelle Blvd., Mississauga, Ont., Canada, L5K 1Z8, Phone (416) 823-8200, Telex 06-982445

APPENDIX D-2-3

SCHLEGEL LINING TECHNOLOGY, INC.

Schlegel

P.O. Box 9115, Station F
Calgary, Alberta T2J 5S7
403-269-1769

SCHLEGEL LINING TECHNOLOGY, INC.

200 South Trade Center Parkway
P.O. Box 7730
The Woodlands, Texas 77380

Tel: (409) 273-3066 (Conroe)
(713) 350-1813 (Houston)
Telex: 792745

February 20, 1984

Mr. Frederick W. Firlotte,
Golder Associates,
500 Nottinghill Road,
London, Ontario. N6K 3P1

Dear Fred:

Re Your Reference 841-3015

Further to our conversation of February 17, I received your written request at 10:30 a.m. today. We will attempt to supply all requested information. Additional helpful items are also enclosed to assist in your very important task.

Schlegel Lining Technology, Inc. successfully completed approximately 800,000 sq. ft. (74,322 m^2) of 100 mil (2.5 mm) in two reservoirs and five monitoring ponds for Key Lake Mining Corporation in 1983. Of interest, this project was commissioned to replace an eight month old 45 mil Hypalon liner which failed for a variety of reasons. Contact names and phone numbers are shown on the list of installed projects.

At present our crews are in the process of mobilization to do the repairs at the Key Lake Mine site which was caused by human error in overfilling both No. 1 and No. 2 reservoir.

Upcoming very soon is a request for tender for Eldor Mines of approximately 222,000 m^2 specified as 80 mil (2.0 mm) for their Collins Bay Rabbit Lake Mine.

I look forward to meeting with you to further discuss our technology.

Sincerely,

Bob Thomson

R.J. (Bob) Thomson,
Canada Accounts Manager.

RJT/gt
Encl.

Schlegel

P.O. Box 9115, Station F
Calgary, Alberta T2J 5S7
403-269-1769

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Budgetary pricing, 1984 cost range, for both Northern Ontario and Saskatchewan. The following is for a complete installation - variances may occur due to exchange rates and/or Union Only project status. (Prices quoted are in Canadian funds.)

Surface area to be covered - 1,000,000 sq. ft. (92900 m^2).
Side slope ratio - 3 to 1.
Pipe penetrations - 2-24" dia.

	80 mil	100 mil
Sheet, Materials & Installation	$1,061,360.00	$1,183,990.00
Duty (Tariff No. C-93902-82)	75,012.00	84,388.50
9% Federal Sales Tax	51,758.28	58,228.07
7% Ontario Sales Tax	43,879.52	49,364.46
Freight (F.O.B. Job Site)	53,640.00	66,010.00
5% Saskatchewan Sales Tax	34,024.51	38,560.83
Duty On Equipment	5,000.00	5,000.00
Total 80 mil (2.0 mm) - Ontario	$1,290,649.80	
- Saskatchewan	$1,280,794.79	
Total 100 mil (2.5 mm)- Ontario	$1,446,981.03	
- Saskatchewan	$1,436,177.40	

SCHLEGEL LINING TECHNOLOGY, INC.

MINIMUM SPECIFICATIONS FOR SCHLEGEL® SHEET - POLYETHYLENE

PROPERTY	TEST METHOD	VALUE
Density	ASTM D792	0.930 gm/cc
Tensile strength @ yield	ASTM D638	1500 psi
Tensile strength @ break	ASTM D638	1500 psi
Elongation @ yield	ASTM D638	10 %
Elongation @ break	ASTM D638	500 %
Stress crack	ASTM D1693	500 hours
Low temperature	ASTM D746	−40 °C
120 day soil burial	ASTM D3083	±10 % of original tensile
Bonded seam strength	ASTM D3083	90 % of material breaking factor
Dimensional stability	ASTM D1204	±3 %

Schlegel® Chemical Resistance

Chemical Resistance Table. Shown here are the results of tests reported by the supplier of high density polyethylene granulate used to manufacture Schlegel® sheet. The high density polyethylene is resistant to the chemicals listed. The degree of chemical attack on any material is influenced by a number of variable factors and their interaction, including temperature, pressure, size of area under attack, exposure duration, and the like. Where sheet will be exposed to a mixture of chemicals it is recommended that tests be carried out for sheet resistance to that chemical mixture. Therefore, these ratings are offered as a guide only.

Abbreviations

S = Satisfactory
U = Unsatisfactory
L = Limited application possible
— = Not tested

Concentration

sat. sol. = Saturated aqueous solution, prepared at 20°C (68°F)
sol. = aqueous solution with concentration above 10% but below saturation level
dil. sol. = diluted aqueous solution with concentration below 10%
cust. conc. = customary service concentration

Medium	Concentration	Resistance at 20°C (68°F)	Resistance at 60°C (140°F)
A			
Acetic acid	100%	S	L
Acetic acid	10%	S	S
Acetic acid anhydride	100%	S	L
Acetone	100%	L	L
Adipic acid	sat. sol.	S	S
Allyl alcohol	96%	S	S
Aluminum chloride	sat. sol.	S	S
Aluminum fluoride	sat. sol.	S	S
Aluminum sulfate	sat. sol.	S	S
Alums	sol.	S	S
Ammonia, aqueous	dil. sol.	S	S
Ammonia, gaseous dry	100%	S	S
Ammonia, liquid	100%	S	S
Ammonium chloride	sat. sol.	S	S
Ammonium fluoride	sol.	S	S
Ammonium nitrate	sat. sol.	S	S
Ammonium sulfate	sat. sol.	S	S
Ammonium sulfide	sol.	S	S
Amyl acetate	100%	S	L
Amyl alcohol	100%	S	L
Aniline	100%	S	L
Antimony trichloride	90%	S	S
Arsenic acid	sat. sol.	S	S
Aqua regia	$HCl\text{-}HNO_3$ 3/1	U	U
B			
Barium carbonate	sat. sol.	S	S
Barium chloride	sat. sol.	S	S
Barium hydroxide	sat. sol.	S	S
Barium sulfate	sat. sol.	S	S
Barium sulfide	sol.	S	S
Benzaldehyde	100%	S	L
Benzene	—	L	L
Benzoic acid	sat. sol.	S	S
Beer	—	S	S
Borax	sat. sol.	S	S
Boric acid	sat. sol.	S	S
Bromine, gaseous dry	100%	U	U
Bromine, liquid	100%	U	U
Butane, gaseous	100%	S	S
Butanol	100%	S	S
Butyric acid	100%	S	L
C			
Calcium carbonate	sat. sol.	S	S
Calcium chlorate	sat. sol.	S	S
Calcium chloride	sat. sol.	S	S
Calcium hydroxide	sat. sol.	S	S
Calcium hypochlorite	sol.	S	S
Calcium nitrate	sat. sol.	S	S
Calcium sulfate	sat. sol.	S	S
Calcium sulfide	dil. sol.	L	L
Carbon dioxide, gaseous dry	100%	S	S
Carbon disulfide	100%	L	U
Carbon monoxide	100%	S	S
Chloracetic acid	sol.	S	S
Carbon tetrachloride	100%	L	U
Chlorine, aqueous solution	sat. sol.	L	U
Chlorine, gaseous dry	100%	L	U
Chloroform	100%	U	U
Chromic acid	20%	S	L
Chromic acid	50%	S	L
Citric acid	sat. sol.	S	S
Copper chloride	sat. sol.	S	S
Copper nitrate	sat. sol.	S	S
Copper sulphate	sat. sol.	S	S
Cresylic acid	sat. sol.	L	—
Cyclohexanol	100%	S	S
Cyclohexanone	100%	S	L
D			
Decahydronaphthalene	100%	S	L
Dextrine	sol.	S	S
Diethyl ether	100%	L	—
Dioctylphthalate	100%	S	L
Dioxane	100%	S	S
E			
Ethane diol	100%	S	S
Ethanol	40%	S	L
Ethyl acetate	100%	S	U
Ethylene trichloride	100%	U	U
F			
Ferric chloride	sat. sol.	S	S
Ferric nitrate	sol.	S	S
Ferric sulfate	sat. sol.	S	S
Ferrous chloride	sat. sol.	S	S
Ferrous sulfate	sat. sol.	S	S
Fluorine, gaseous	100%	U	U
Fluosilicic acid	40%	S	S
Formaldehyde	40%	S	S
Formic acid	50%	S	S
Formic acid	98-100%	S	S
Furfuryl alcohol	100%	S	L
G			
Gasoline	—	S	L
Glacial acetic acid	96%	S	L
Glucose	sat. sol.	S	S
Glycerine	100%	S	S
Glycol	sol.	S	S
H			
Heptane	100%	S	U
Hydrochloric acid	10%	S	S
Hydrobromic acid	50%	S	S
Hydrobromic acid	100%	S	S
Hydrochloric acid	10%	S	S
Hydrochloric acid	concentrated	S	S
Hydrocyanic acid	10%	S	S
Hydrofluoric acid	60%	S	L
Hydrofluoric acid	4%	S	S
Hydrogen	100%	S	S

Medium	Concentration	Resistance at 20°C (68°F)	Resistance at 60°C (140°F)
Hydrogen peroxide	30%	S	S
Hydrogen peroxide	90%	S	U
Hydrogen sulfide, gaseous	100%	S	S
L			
Lactic acid	100%	S	S
Lead acetate	sat. sol.	S	—
M			
Magnesium carbonate	sat. sol.	S	S
Magnesium chloride	sat. sol.	S	S
Magnesium hydroxide	sat. sol.	S	S
Magnesium nitrate	sat. sol.	S	S
Maleic acid	sat. sol.	S	S
Mercury	100%	S	S
Mercuric chloride	sat. sol.	S	S
Mercuric cyanide	sat. sol.	S	S
Mercuric nitrate	sol.	S	S
Methanol	100%	S	S
Methylene chloride	100%	L	—
Milk	—	S	S
Molasses	cust. conc.	S	S
N			
Nickel chloride	sat. sol.	S	S
Nickel nitrate	sat. sol	S	S
Nickel sulfate	sat. sol.	S	S
Nicotinic acid	dil. sol	S	—
Nitric acid	25%	S	S
Nitric acid	50%	S	U
Nitric acid	75%	U	U
Nitric acid	100%	U	U
O			
Oils and Grease	—	S	L
Oleic acid	100%	S	L
Orthophosphoric acid	50%	S	S
Orthophosphoric acid	95%	S	L
Oxalic acid	sat. sol	S	S
Oxygen	100%	S	L
Ozone	100%	L	U
P			
Petroleum	—	S	L
Phenol	sol.	S	S
Phosphorus trichloride	100%	S	L
Photographic developer	cust. conc.	S	S
Picric acid	sat. sol	S	—
Potassium bicarbonate	sat. sol.	S	S
Potassium bisulfate	sat. sol.	S	S
Potassium bisulfide	sol.	S	S
Potassium bromate	sat. sol	S	S
Potassium bromide	sat. sol.	S	S
Potassium carbonate	sat. sol.	S	S
Potassium chlorate	sat. sol.	S	S
Potassium chloride	sat. sol.	S	S
Potassium chromate	sat. sol.	S	S
Potassium cyanide	sol.	S	S
Potassium dichromate	sat. sol.	S	S
Potassium ferricyandide	sat. sol.	S	S
Potassium ferrocyanide	sat. sol.	S	S
Potassium fluoride	sat. sol.	S	S
Potassium hydroxide	10%	S	S
Potassium hydroxide	sol.	S	S
Potassium hypochloride	sol.	S	L
Potassium nitrate	sat. sol.	S	S
Potassium orthophosphate	sat. sol.	S	S
Potassium perchlorate	sat. sol.	S	S
Potassium permanganate	20%	S	S
Potassium persulfate	sat. sol.	S	S
Potassium sulfate	sat. sol.	S	S
Potassium sulfite	sol.	S	S
Propionic acid	50%	S	S
Propionic acid	100%	S	L
Pyridine	100%	S	L
Q			
Quinol (Hydroquinone)	sat. sol.	S	S

Medium	Concentration	Resistance at 20°C (68°F)	Resistance at 60°C (140°F)
S			
Salicylic acid	sat. sol.	S	S
Silver acetate	sat. sol	S	S
Silver cyanide	sat. sol.	S	S
Silver nitrate	sat. sol.	S	S
Sodium benzoate	sat. sol.	S	S
Sodium bicarbonate	sat. sol.	S	S
Sodium biphosphate	sat. sol	S	S
Sodium bisulfite	sol.	S	S
Sodium bromide	sat sol	S	S
Sodium carbonate	sat sol	S	S
Sodium chlorate	sat. sol.	S	S
Sodium chloride	sat. sol.	S	S
Sodium cyanide	sat. sol.	S	S
Sodium ferricyanide	sat. sol.	S	S
Sodium ferrocyanide	sat. sol.	S	S
Sodium fluoride	sat sol	S	S
Sodium fluoride	sat sol	S	S
Sodium hydroxide	40%	S	S
Sodium hydroxide	sat sol	S	S
Sodium hypochloride	15% active chlorine	S	S
Sodium nitrate	sat sol	S	S
Sodium nitrite	sat sol.	S	S
Sodium orthophosphate	sat sol	S	S
Sodium sulfate	sat sol	S	S
Sodium sulfide	sat sol	S	S
Sulfur dioxide, dry	100%	S	S
Sulfur trioxide	100%	U	U
Sulfuric acid	10%	S	S
Sulfuric acid	50%	S	S
Sulfuric acid	98%	S	U
Sulfuric acid	fuming	U	U
Sulfurous acid	30%	S	S
T			
Tannic acid	sol	S	S
Tartaric acid	sol	S	S
Thionyl chloride	100%	L	U
Toluene	100%	L	U
Triethylamine	sol	S	L
U			
Urea	sol	S	S
Urine	—	S	S
W			
Water	—	S	S
Wine vinegar	—	S	S
Wines and liquors	—	S	S
X			
Xylene	100%	L	L
Y			
Yeast	sol.	S	S
Z			
Zinc carbonate	sat. sol.	S	S
Zinc chloride	sat. sol	S	S
Zinc (II) chloride	sat. sol.	S	S
Zinc (IV) chloride	sat. sol	S	S
Zinc oxide	sat. sol.	S	S
Zinc sulfate	sat. sol.	S	S

Specific immersion testing should be undertaken to ascertain the suitability of chemicals not listed above with reference to special requirements.

TASC
THE ANALYTIC SCIENCES CORPORATION

One Jacob Way, Reading, MA 01867, tel. 617-944-6850

December 16, 1981

Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94303

Attention: Dr. Robert F. Williams

Subject: Radiation Damage to Polyethylene

Dear Bob:

In answer to your question regarding the susceptibility of polyethylene high integrity containers for LLW to radiation damage, this is not likely to be a problem. Changes in the mechanical properties of polyethylene occur at radiation doses of about 10^{10} rads. Over a 1000 year period, that is 27000 r/day. For radiation averaging 0.5 Mev, the concentration of radioactive materials in the LLW would have to be about 2000 $\mu Ci/cm^3$ to yield that dose.

A look at Table 1 in 10 CFR 61 which gives maximum nuclide concentrations for various classes of LLW, shows that only cobalt-60, cesium-137, and tritium can approach the damaging concentration. Tritium has a very low energy beta emission (much less than the 0.5 Mev used in our rough calculation) and both cesium and cobalt have short life-times relative to 1000 years. Thus, unless extraordinary concentrations of these isotopes are buried, no serious radiation damage should occur to polyethylene over the container's life-time.

Hope this approximate calculation gives you the information you needed. If not please call me.

Very truly yours,

THE ANALYTIC SCIENCES CORP.

Tom

Dr. Thomas J. Kabele

TJK/mf

4. MATERIAL SUITABILITY

Polyethylene is a thermoplastic material which may be produced in either a low density or high density form, depending upon the manufacturing process used. "As a general class of materials, polyethylene is noted for (a) outstanding dielectric properties, (b) excellent chemical resistance to solvents, acids and alkalies, (c) toughness, (d) good barrier properties, and (e) their relative adaptability to various processing techniques. These properties can be adjusted and other desirable properties can be obtained through tailoring of the molecular structure and the incorporation of additives" (Reference 3). Thus, it is not surprising that of the many packaging materials readily available, polyethylene was considered an attractive alternative for the development of an HIC.

To determine the suitability of polyethylene for this particular application, four areas were investigated: (a) its radiation resistance and resulting effects on tensile strength, elongation, and environmental stress cracking; (b) chemical resistance under burial conditions; (c) fire resistance; and (d) ease of manufacturing.

a. Resistance and Effects of Radiation on Polyethylene

The type of polyethylene used in the manufacturing of the HIC is Marlex CL-100, a product of the Phillips Chemical Company or G-PEP-805, a product of Union Carbide. Marlex CL-100 is a high density polyethylene which becomes cross-linked when exposed to radiation. "This cross-linking gives products that have excellent resistance to stress cracking and chemical attack, excellent impact strength, weathering characteristics and overall toughness." (Reference 4.)

In TSM-244, a technical service memorandum published by the Phillips Chemical Company in November 1977, it is stated that Marlex CL-100 has "sufficient melt strength to support itself at temperatures up to 400°F." TSM-244 further explains that "the most outstanding property of these cross-linked resins is their environmental stress cracking resistance (ESCR)....the ESCR of Marlex CL-100 is greater than 1,000 hours when measured by the standard ASTM D1693 test, sometimes referred to as the Bell Bent Strip Test. A value of greater than 1,000 hours is indicative of outstanding ESCR and even exceeds the requirements of resins used in the wire and cable industry, pipe and other demanding engineered applications."

"The amount of damage to a polymer by radiation is generally dependent upon the total dose absorbed regardless of the type of radiation" (Reference 5). Minor degradation of Marlex CL-100 and G-PEP-805 polyethylene begins to occur at $\geq 10^{8}$ Rads (Reference 6, page 21). It is estimated that over the 300 year life of the HIC the total accumulated dose will be 8.5×10^{7} Rads. This is based on a specific activity of 1,340 micro-Ci/gm which is approximately four times the average of the maximum activity levels recently recorded at Peach Bottom.

Reference 13 discusses the weatherability of various grades of Marlex CL-100. Grade CL-100 JZ is used for the HIC. The relative transparency of this material allows the determination of contents level with a back light.

The most accurate indication of sunlight resistance is the Atlas weather-ometer hour indication. In the case of CL-100 JZ, this value of intense sunlight exposure prior to degradation is 5,000 hours. While it is difficult to relate this directly to actual sunlight exposure, a conservative estimate may be 2 to 4 years as indicated by Phillips Chemical Company. The UV resistance of G-PEP-805 is in excess of 5 years.

The HICs will be stored indoors whenever possible at both the manufacturer's location and the Peach Bottom Site; in any case, to allow flexibility to the burial site operators, no container will be used if it was manufactured more than 12 months prior to filling at Peach Bottom without documentation verifying actual storage conditions.

The date of manufacture is directly traceable by the HIC's unique container number. This container age verification is part of the PECO plant procedures concerned with the use of HICs at Peach Bottom.

b. Chemical Resistance

"Although only a very few chemicals will react with Marlex High Density Polyethylene (MHDPE), lack of reactivity does not ascertain that a material will not be affected by its environment. The possibility of material solubility remains and could possibly result in loss of strength and swelling of the polyethylene if the chemical is absorbed by the polyethylene, or loss of strength if the polyethylene is soluble in the chemical. To define the effects of this nature, immersion tests have been performed using a number of chemicals which represent most of the types of liquids in common use" (Reference 6). At temperatures of 80-120, and 150°F, and after exposure to these chemicals for 3 months, the tensile strength and elongation of the polyethylene specimens were measured to see if any changes had occurred. The results presented in TSM-243 (July 1975 by Phillips Chemical Company) showed the excellent chemical resistance of polyethylene (Reference 6). None of these solvents are present in the waste material or its degradation by products.

The waste resins to be stored in the HICs, such as polystyrene beads, are noncorrosive. Yet when irradiated with significant doses of radiation, polystyrene generates a gas and an acid (HCL). From TSM-189, polyethylene was found to perform satisfactorily with various concentrations of HCL liquids used as reagents (Reference 9).

While the solvents listed in References 6 and 9 are common in certain industries, these solvents are not common to the facility at which the HIC will be used. Administrative control (plant procedures and vendor QA program) do not allow for containerization or external cleaning of HICs with any item other than that which is allowed by specification or as approved by Phillips Chemical Company or Union Carbide.

In addition to chemical resistance, polyethylene has been fungus tested with no evidence of deterioration (Reference 6).

Under burial site conditions, polyethylene has been demonstrated to be stable in many applications. Thus, polyethylene, particularly Marlex CL-100 and G-PEP-805 are extremely chemical- and corrosion-resistant materials.

c. Fire Resistance

A flammability test was performed by Underwriters Laboratories to determine the flammability of polyethylene. The test, called Arcing Ignition, subjected a sample of polyethylene to 40 applications per minute, for a maximum of 5 minutes, of an electric arc fed by a 33-amp current from a 240-Volt power supply. These results are tabulated below (taken from TSM-243, July 1975, Phillips Chemical Company, Bartlesville, Oklahoma - Reference 6) for a polyethylene.

Distance of Electrodes from Surface, Inches	Number of Arcs Req'd To Ignition
0	79-182
1/16	49-57
1/4	70-200
1/2	200+

It is also reported that the burn rate of polyethylene, should it ignite, is 1.04 in/min. For flash ignition of polyethylene to occur, the ignition temperature would be 645°F, and for self-ignition the ignition temperature would be 1,058°F.

d. Manufacturing of HIC

The HIC is made by the rotational molding technique, "a method of powder molding by which a wide variety of large or small items are produced in a rotating mold." The rotational molding process has many unique features that would cause it to be selected over some of the older, more widely used molding processes. Some of the more desirable features are:

(1) Economy

(2) Ease of Processing

(3) High Quality Parts

The absence of postive pressure in the powder molding process places certain limits on the type of resin that can be used. The high molecular weight resins used for blow molding and sometimes injection molding cannot be rotationally molded because they do not flow out in the absence of pressure to form a homogeneous part. This one limitation had made it difficult for rotationally molded polyethylene to compete in certain applications.

Marlex CL-100 and G-PEP-805, polyethylene resins, have helped to overcome this limitation by making it possible for the rotational molder to produce high quality parts, large or small, that withstand severe service applications. These resins represent a significant breakthrough since they are the first rotational molding resins with sufficient stress cracking resistance for severe service, yet still have excellent moldability.

"In the rotational molding process a cold mold is filled with a powdered resin. The mold is placed in an oven and rotated simultaneous about two perpendicular axes. During this stage, a uniform layer of resin is deposited on the mold. After sufficient time has elapsed to properly fuse the resin, and while it is still rotating, the mold is cooled. This can be accomplished with forced cool air, atomized air-water fog, water spray, or a combination of these methods. After cooling, the part is removed from the mold and more resin is added to start the cycle again." (Reference 7)

WESTERN RADIATION CONSULTANTS, INC. Industrial, Medical, Environm

1306 Winfield Drive
Fort Collins, Colorado 80526
303-482-3029

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22 1980

1980

Project 79057

July 6, 1980

[illegible]
[illegible]
Denver, CO 80223

Attention: [illegible]

STATEMENT

Fee for Professional Service:

1. Prepatation of an experiment to test adequacy of the Schlegel polyethylene liner for minimizing Radon-222 diffusion.

TOTAL

James E Johnso

James E. Johnson, Ph.D., Certified Health Physicist   Janet A. Johnson, M.S., Certified Health Physicist   Hilding G. Olson, Ph.D., Nuclear Engine
F. Ward Whicker, Ph.D., Radioecologist

WESTERN RADIATION CONSULTANTS, INC. Industrial, Medical, Environmental

1306 Winfield Drive
Fort Collins, Colorado 80526
303-482-3029

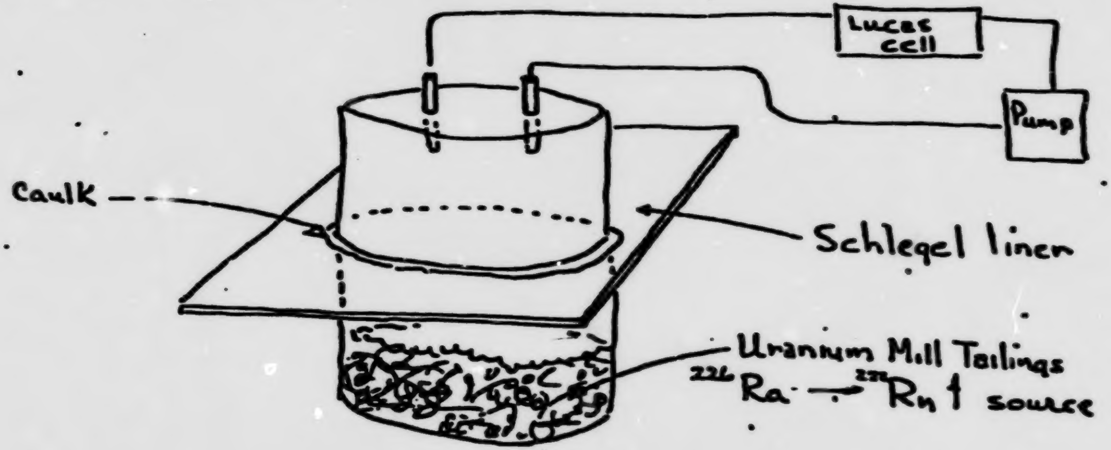
July 6, 1980

[illegible]
[illegible]
Denver, CO 80223

Attention:

Dear Al:

As you requested we have tested the Schlegel polythylene liner as a barrier to the diffusion of Radon in soil. A Schlegel sheet was obtained from Fred A. Staab and an experiment was designed as shown in the following diagram.



The liner was sealed with silicone to the top of an open bucket containing dry Uranium mill tailings. An identecal empty bucket with sampling ports was sealed to the top of the liner. After a period of three days samples were taken with Radon flasks (lucas chambers) and the radon concentration in the top bucket was measured by standard ZnS(Ag) scintillation counting. The results were as follows for 3 seperate determinations.

Radon concentration above liner was less than 1 pCi/Liter.

James E. Johnson, Ph.D., Certified Health Physicist   Janet A. Johnson, M.S., Certified Health Physicist   Hilding G. Olson, Ph.D., Nuclear Engineer, P.E.
F. Ward Whicker, Ph.D., Radioecologist

Radon Concentration without the liner would be greater than 2000 pCi/Liter at steady state conditions.

On the basis of the above results it is our conclusion that the Schlegel liner is an adequate barrier to prevent diffusion of Radon. The Schlegel liner will be adequate for the proposed new building design if used in conjuction with other standard techniques to prevent radon diffusing from the contaminated soil from reaching any building interior space above.

It should be pointed out that the long-term characteristics of the Schlegel liner are not known but perhaps may be inferred from other test data of Schlegel and Co.

TESTING OF SCHLEGEL® SHEET IN A URANIUM LIQUOR SOLUTION

Introduction:

A solution was submitted by Gulf Seal Corporation for compatibility testing against SCHLEGEL® Sheet. The solution as listed by analysis was composed primarily of salts and metals. No organic compounds were listed.

Test Method:

Samples of SCHLEGEL® Sheet were totally immersed in the solution as provided. Testing occurred over six weeks at 158° F according to LP-0420.

Results:

The total weight gain after exposure for six weeks was +.76%.

Changes in tensile properties are listed as follows:

$\Delta \Sigma$ Yield = -.23%

Δ E Yield = 0

$\Delta \Sigma$ Break = +1.71%

Δ E Break = 0

Conclusions:

The test data indicate SCHLEGEL® Sheet to be resistant to chemical attack from this solution. The change in tensile properties lie within the ±10% range allowable. The weight change lies within the ±3% range allowable. SCHLEGEL® Sheet will have no problem performing as a long term impermeable membrane liner to this solution.

Charles Crisman
January 26, 1982

TENSILE PROPERTIES

Control Specimens:

	Σ Yield (lb/in^2)	E Yield (%)	Σ Break (lb/in^2)	E Break (%)
(1)	3141.79	15	3940.49	987.5
(2)	3035.24	15	3833.99	987.5
(3)	3069.03	15	3926.15	987.5
(4)	3151.98	15	3926.15	987.5
(5)	2990.51	15	3910.67	987.5
Average:	3077.70	15	3907.49	987.5

Test Specimens:

	Σ Yield (lb/in^2)	E Yield (%)	Σ Break (lb/in^2)	E Break (%)
(1)	3183.58	15	4107.84	987.5
(2)	3029.53	15	3851.10	987.5
(3)	3029.53	15	3902.45	987.5
(4)	3132.23	15	4005.14	987.5
(5)	2978.19	15	4005.14	987.5
Average:	3070.61	15	3974.33	987.5

Change in Tensile Properties (Δ%):

	Σ Yield (lb/in^2)	E Yield (%)	Σ Break (lb/in^2)	E Break (%)
	-.23	0	+1.71	0

GENERAL SPECIFICATIONS FOR HDPE LINING

I. GENERAL REQUIREMENTS

A. Scope

The work covers the manufacture and installation of a High-Density Polyethylene (HDPE) liner for the lining of earthen basins for the protection of ground water.

The work includes furnishing all labor, superintendence, tools, construction machinery and materials which may be necessary to construct the project as described in these specifications.

The Lining Contractor's approved drawings for construction will specify all components and details required to meet specifications whether the responsibility of the Owner or the Lining Contractor.

B. Experience

The manufacturer/installer must have at least five (5) years continuous experience in the manufacture and installation of the type of liner described in these documents, and must have manufactured and installed at least 10,000,000 square feet of the material specified for this project.

The manufacturer/installer shall submit with the shop drawings a list of ten (10) similar installations which have been in service at least two (2) years. The list shall include the owner's name, location of project, square feet of product installed, and the completion date. Shop drawings not including this required information will not be accepted.

C. Submittals

1. Samples: Submit for approval samples of the liner material for customer review and testing. Testing shall include compatibility analysis by material supplier or owner.

2. Shop Drawings: Submit for approval as soon as practical after award of the contract, six (6) sets of full and complete shop and installation drawings showing a minimum of:

   (a) Layout of the liner system.

   (b) Details of jointing, liner system, liner anchorages to concrete structures, details of sealing the lining material to concrete structures and any other openings into the structure.

3. Certificates: Certificates of compliance with the requirements of standards and testing methods specified herein shall be submitted prior to delivery. The liner material manufacturer must satisfy by affidavit to the Owner and Contractor, jointly, that the material he offers to furnish and install will meet in every aspect the requirements set forth in the specifications. The Contractor shall transmit to the Owner the affidavit given him by the manufacturer or supplier prior to approval for the furnishing and installing of any such material.

4. Schedules: The Contractor shall submit a schedule detailing the liner fabrication and installation.

D. Delivery, Storage and Handling of Materials

1. Delivery: Materials shall be delivered to the site after the required submittals have been approved.

2. Storage and Handling: Storage and handling of the materials shall conform to the manufacturer's recommendations and shall be done in such a manner as to prevent damage to any part of the work.

E. Reference Standards

Reference Standards shall comply with the applicable provisions and recommendations of the American Society for Testing Materials (ASTM), except as otherwise shown or specified.

TABLE 1

TYPICAL PHYSICAL PROPERTIES OF HDPE LINER

Property	Test Method	Value	Units
Density	ASTM D-792 Method B	0.94 0.94	g/cm^3
Melt Flow Rate	ASTM D-1238 Condition E	0.2	g/10 min.
Average Molecular Weight	ASTM D-2857	1.5×10^5	--
Coefficient of Linear Thermal Expansion	ASTM D-696	1.2×10^{-4}	°C^{-1}
Water Absorption	ASTM D-570	0.085	%/4 days
Shore D Hardness	ASTM D-2240	65	Shore D
Impact Resistance Notched	ASTM D-256 Method B	No break	ft.lb/inch of Notch
Percentage Elongation at Yield	ASTM D-638 Speed C Test Specimen Type IV	15	%
Percentage Elongation at Break		800	%
Tensile Stress at Yield		2,800	psi
Tensile Strength at Break		4,500	psi
Thickness	ASTM D-374	0.060, 0.080, and 0.100	in.

F. Metal Fastenings

Product and Manufacturer: Provide alloy steel fasteners as manufactured by the following:

1. Molly Parabolts by USM Corporation
2. Kwik-Bolt by Hilti Corporation
3. Ramset, Inc.
4. Or Approved Equal.

G. Asphalt Cement

Wet or dry elastic roof sealer as manufactured by MONSEY PRODUCTS, INC.

III. INSTALLATION SPECIFICATIONS

A. Inspection of Sheet Liner at Job Site

The Lining Contractor shall be responsible for inspection of the sheet rolls at arrival at the job site. Should rolls show damage from transit, they will be so identified by the Lining Contractor and set aside.

During unrolling of the lining material, the Lining Contractor will carry out visual inspection of the sheet surface. Any faulty areas shall be repaired in a approved manner by the Lining Contractor.

B. Area Subgrade Preparation

The surface of the bottom and side slopes in contact with the membrane liner shall be free of broken stones or hard objects within 4 inches of the surface. Stones larger than 2 inches in diameter shall not be permitted within 4 inches of the surface. Surface must be compacted as required by Purchaser.

The surface of all concrete bonding surfaces shall be cleaned and smoothed prior to anchoring the liner.

C. Installation

1. General: The HDPE liner shall be laid out and installed by manufacturer's trained technicians in accordance with the applicable approved shop drawings.

   The sheets shall be placed in the basin to permit termination at the top of the side slopes and adjacent to concrete structures and pipe conduits as shown on the drawings. The layout shall be designed to minimize the number and length of the field joints, consistent with proper methods of liner installation.

F. **Job Conditions**

Prior to installation of the liner, Contractor shall verify conditions of existing facilities and structures to ensure an adequate subgrade for the liner, as specified in Section III.B of this document.

G. **Testing**

Destructive and non-destructive testing are carried out by trained personnel of the Lining Contractor. Quality Control procedures are specified in Section IV following.

H. **Warranty**

Terms and conditions of warranty to be agreed upon between the Owner and the Lining Contractor.

II. MATERIAL SPECIFICATIONS

A. **Sheet Liner**

The lining shall be a high density polyethylene (HDPE) containing no additives, fillers or extenders. Carbon black 2% ± .5% shall be added to the resin for ultra-violet resistance. The lining system shall be manufactured, furnished and installed by a single contractor. Typical physical properties of the HDPE Liner are described in Table 1 on the preceding page.

B. **Extrusion Joining Resin**

Resin used for extrusion joining sheets and sheet to pipe shall be HDPE produced from and the same as the sheet resin. Physical properties shall be the same as those of the resin used in the manufacture of the HDPE liner. The resin shall be supplied in black.

C. **Sponge Rubber Sheeting**

Sponge rubber sheeting shall be type SCE-41, Neoprene/EPT/SBR, Closed Cell Medium, 1/4 inch thick, one side adhesive.

D. **Neoprene Adhesive**

PYTHON, neoprene adhesive shall be used for gluing sponge rubber sheeting to concrete and HDPE surfaces.

E. **Metal Battens**

Batten strips shall be No.12 gauge steel type A-36. Width of strips shall be two inches minimum.

F. **Metal Fastenings**

Product and Manufacturer: Provide alloy steel fasteners as manufactured by the following:

2. Field Joints:

(a) General: Field joints shall be made by overlapping adjacent sheets a minimum of eight (8) inches and extruding a ribbon of extrusion joining resin no less than 1.5 inches in width between the overlapped sheets or over the seam between the sheets where hand welds are required.

Prior to extrusion welding of the seams, all areas which are to become seam interfaces shall be cleaned of dust and dirt. The slick surfaces of the HDPE sheet which are to become seam interfaces shall be roughened with a wire brush or other acceptable means before extrudate is placed between the overlapping sheets or over a lapped seam.

Extrusion joining shall not take place unless the sheet is dry and shall not take place unless the ambient temperature is above 45°F and below 90°F.

(b) Field Joints: Joints between the lining sheets shall be field welded using the manufacturer's extrusion joining equipment and techniques. The joining procedure shall consist of softening the liner material by heated air. The temperature of the air impinging on the sheet for this purpose shall range from 420°F to 680°F. The exact temperature used shall be determined by the installation supervisor. Directly following the application of heat, a one and one-half inch minjmum width strip of the same high density polyethylene resin from which the sheet is made shall be extruded between the overlapped sheets. The temperature of the resin as it emerges from the extrusion die shall range from 428°F to 536°F. The overlapped sheets are then pressed together to form the extrusion joint.

(c) Penetrations of Liner Material: Penetrations through the liner for pipe flashings, patches, etc. shall be field welded using an extrusion hand welder. The joining procedure shall consist of softening the liner material by heated air as above described. Directly following the application of heat, a hot strip of the same material from which the sheet is made will be extruded over the joint to produce the extruded joint.

Any required repair of small holes in the liner surface shall be made with the extrusion hand welder. Liner material shall be cleaned of all dirt, dust and other foreign material, all smooth HDPE surfaces roughened, air heated to the prescribed temperature, and a strip of HDPE resin extruded over the hole to produce an extruded welded repair.

Seals around penetrations shall be made as described below.

All pipe penetrations shall be sleeved with HDPE pipe. Each HDPE pipe sleeve shall be sealed to the liquid carrying pipe to prevent leakage. The basin liner shall be anchored to a concrete collar surrounding the penetration. An HDPE apron shall be extrusion welded to the pipe sleeve and shall be extrusion welded to the base sheet outside of the area where the base sheet is anchored to the concrete collar.

IV. QUALITY CONTROL SPECIFICATIONS AND PROCEDURES

A. Quality Control of Raw Material by its Manufacturer

The manufacturer of the HDPE resin used in sheet production tests each batch before delivery to ensure a maximum consistency of raw material quality.

The following tests are carried out by the producer of the raw material on each batch and the results forwarded to the sheet fabricator:

1. Density per ASTM Designation D-792-66: The density of the material reflects the degree of crystallinity and thus serves as an indirect check on mechanical qualities such as hardness, stiffness, and tensile strength.

2. Carbon Black Content per ASTM Designation D-1603-76: Carbon black polyethylene serves primarily as protection against thermal aging and harmful ultraviolet radiation, present in outdoor weathering. Thus, quality control of the carbon black content ensures the good weathering properties of polyethylene.

3. Melt Index per ASTM Designation D-1238-73: A material's melt index is a measure of its mean molecular weight and rheological properties. Thus, holding the melt index of the base material within a narrow range is a criterion for uniform and optimum HDPE liner production.

4. Relative Solute Viscosity per ASTM Designation D-3593-77: This test monitors a plastic's mean degree of polymerization and mean molecular size - ensuring their consistency. As above, these values affect the consistency of processing and mechanical properties of the resulting product.

5. Bell Test per ASTM Designation D-1693-70: Bell testing is a relatively fast method of testing a material's resistance to stress cracking. This test evaluates a material's performance under mechanical stressing in aggressive media.

6. Moisture Content per ASTM Designation D-570-63: Maintaining a constant moisture content in the base material is necessary for processing resulting in a pore-free, bubble-free product. Employing only material with a moisture content in a narrow tolerance range is another requirement for consistent product quality.

The data determined is evaluated by the manufacturer and, if deviating from the agreed tolerance ranges, the tested batch is not delivered. As a result of this testing, the manufacturer is guaranteed consistent base material quality, essential in the light of the demanding conditions prevailing in the various applications of HDPE liners.

B. Quality Control of the Incoming Raw Material by Sheet Manufacturer

The incoming raw material is again sampled and tested, this time in the lab facilities of the sheet manufacturer. As before, properties relative to processing are determined, specifically:

Melt Index per ASTM Designation D-1238-73

Density per ASTM Designation D-792-66

Moisture Content per ASTM Designation D-570-63.

This testing provides further verification of consistent product quality, supplementary to the manufacturer's certificate.

If the test results are positive, a sample of the batch is processed in manufacturing and evaluated as to melting behavior, forming behavior and the product sheet's visual appearance.

No batch is sent into production before positive results are obtained for the incoming base material and the test processing. If negative results are obtained, the batch is excluded from processing and returned to the manufacturer.

All properties determined in these tests are compiled in the final sheet certificate.

C. Quality Control of Sheet Production

Automatic control is a feature especially valued in the extrusion process and the successive processing stages. Important parameters in all stages of processing are controlled by automatic control systems and indicated by pen recorders.

Three different qualities of the sheet are inspected continuously during production:

- Forming Process
- Surface Appearance
- Sheet Thickness

At least three random samples are taken from each sheet roll and forwarded to the laboratory for extensive testing. The sample sites are distributed to ensure a representative evaluation of the overall quality.

The following tests are carried out for each sheet:

- Tensile Testing per ASTM Designation D-638
- Impact Tensile Testing per ASTM Designation D-638
- Thickness
- Stress Cracking Resistance (Bell Test) per ASTM Designation D-1693-70.

The following supplementary tests are carried out for sheet samples from each raw material batch:

- Melt Index per ASTM Designation D-1238-72
- Thermal Shrinkage per ASTM Designation D-696
- Density per ASTM Designation D-792-66.

This testing effects a permanent surveillance of the production process and constant product quality.

Narrow tolerance ranges ensure high quality in production. Products deviating from these ranges are removed and the cause determined.

D. Quality Control of Installation

Sheet installation work is carried out under painstaking supervision up to and including project completion.

The quality control is carried out by the on-site engineers as well as outside testing institutions.

Quality control of installation can be divided into three areas:

1. Checking the sheets delivered to site for transport damages, check of sheet identification number with number on certificate.
2. Inspection and continuous control of all welding process parameters.
3. Testing of the completed weld seams.

On-site welding of the liner is carried out by an extrusion welding process. This process guarantees consistent weld seam quality within a wide range of ambient conditions. The control system of the welding machines are extensively automated to enable monitoring of the welding process by the operating personnel.

The welds are made in one procedure by means of an automatic welding machine, which preheats the welding surfaces to the desired temperature, injects a ribbon of molten HDPE material and then applies contact pressure to the seam.

The procedure for fillet welds is similar in that the welding area is preheated and the welding material is molten HDPE. The necessary contact pressure comes from the weight of the hand welding unit itself. Fillet welds are used only for repair work and special designs.

Test welds are run preceding all extensive welding to assure good weld quality under the prevailing site conditions; these weld samples are subsequently subjected to mechanical testing.

1. Visual Inspection of Welded Seam: The main prerequisite for good bonding is continuous monitoring of the welding process parameters, such as hot air temperature, welding speed and contact pressure. This is best carried out by specially trained personnel. Visual inspection of the welding surfaces, the welding process and the completed weld by experienced plastic welders allows a reliable evaluation of seam quality.

2. Quality Control of Welding Seams: Production of a quality welding seam starts with a preliminary test weld. The machine settings, pretreatment of the weld surfaces and adjustment to environmental effects are all tested on a sample welding seam. A hand operable tensile testing machine enables on site confirmation of the joint's tensile strength using strip samples.

   After installation, two major types of quality control are available for testing the seams:

   - destructive material tests of weld samples (spot check)
   - non-destructive material tests of all welding seams.

3. Determination of Mechanical Strength

   (a) Tensile and Peel Tests: Because it would be uneconomical to conduct destructive tests on all weld seams, destructive tests are conducted only on a spot check basis. Extensive site experience has shown that two samples daily are sufficient for evaluation purposes. These samples are then tested by Quality Control or independently by official government testing agencies.

   (b) Point Stressing: Point stressing of the newly produced weld is sufficient to locate areas of adhesion (i.e., not fully bonded). This is done by running a screw driver or similar device along the weld seam between the lower sheet and the extrudate.

4. Testing of Seal Continuity: After installation, the large size of the completed liner system permits testing only from the upper side of the liner. This restriction considerably reduces the number of reliable testing procedures. However, two non-destructive testing methods can be used to verify the continuity (watertightness).

GENERAL SPECIFICATIONS FOR HDPE LINING

(a) Vacuum Test: One method of testing the seal is vacuum testing. In this test, the weld seam is placed under a vacuum using a clear plastic suction cup attached to a vacuum pump. A foaming agent indicates the exact position of any leaks encountered.

(b) Ultrasonic Testing: Ultrasonic testing is just as reliable as vacuum testing and in addition provides information on the homogeneity of the welding seam. Easy handling and a greater testing speed are further advantages of this method.

Site Preparation

The contractor will prepare the site in accordance with the standards agreed to by the design engineer in cooperation with Schlegel, as stated in their contract specification.

The areas to be lined may be prepared from graded or natural material that is compacted by rolling or vibration to an even surface. The area must be free of major protrusions, such as rock outcrops or tree stumps. The standard for the finished surface will be dictated by the live and dead weight loadings to which the lining will be subjected during installation and service.

Pipe works, weirs, sumps or other rigid structures that have been designed to pass through the **Schlegel®** sheet will also be finished before the lining work begins. The securing trench on the embankment crown may be excavated before or during the lining operation.

The site must not accumulate water during the installation period, and local sumps may be required in the lined area to assist de-watering.

Under-sheet drainage may take the form of piping or a coarse gravel layer laid to falls.

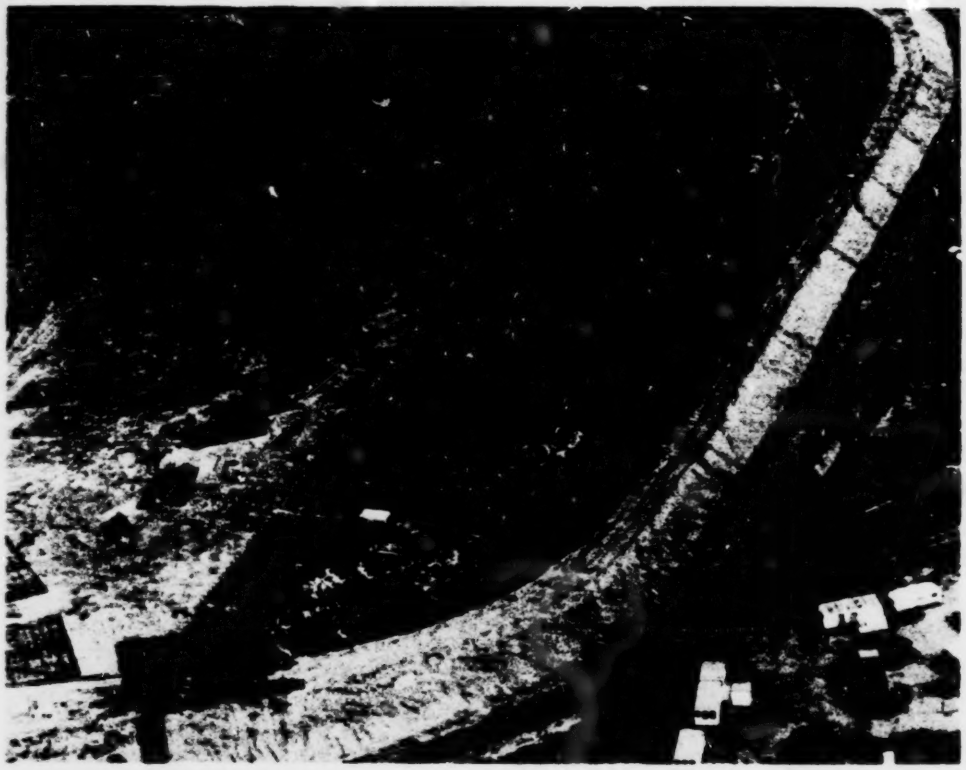
Embankments must be stabilized within the angle of repose of the soil. Rock outcrops should be over-excavated and replaced to level with selected media followed by compaction.

Services by General Contractor

All or some of the following services may be requested from the general contractor to facilitate the installation of the **Schlegel®** lining system:

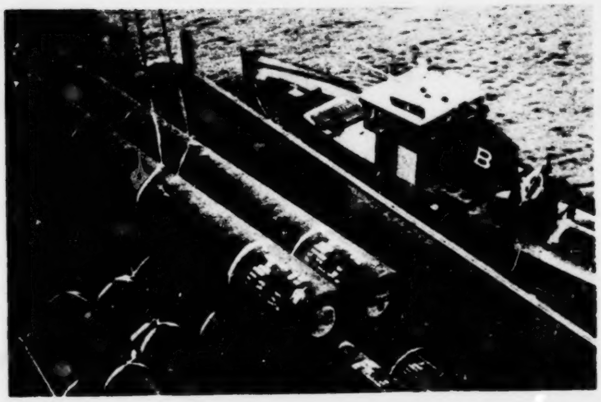
1. Unloading delivered materials at job site
2. Provision of open temporary storage area for delivered sheet
3. Provision of covered storage area for electrical plant and equipment
4. Transportation of rolls from temporary storage to the installation site
5. Provision of a vehicle for unrolling the **Schlegel®** sheet rolls
6. Excavation and subsequent backfilling of the perimeter securing trench
7. Maintenance of the site in a de-watered condition
8. Additional general labor for short periods (chargeable at day work rates).

The individual details for a particular site will be specified at the time of offer.



Typical scenes during the installation of SCHLEGEL lining systems.

Material Transportation and Handling



Each roll of **Schlegel®** sheet weighs up to 5 tons, depending on sheet thickness. A roll may be lifted by slings or chains from two points in the center of the roll. Rolls will be delivered to the site in a flat-bed truck or container that carries up to four rolls—92,000 ft² (2.1 acres) of sheet.

If a crane is not readily available, earth-moving vehicles, such as front-end loaders or backhoes may be used for unloading. The same equipment will then be used to transport the roll to its position at the site, and to unroll it.

Sheet is shipped in secured rolls, without external packing.

Vehicles including many types of site front bucket loaders may be used for both positioning and unrolling the sheet.

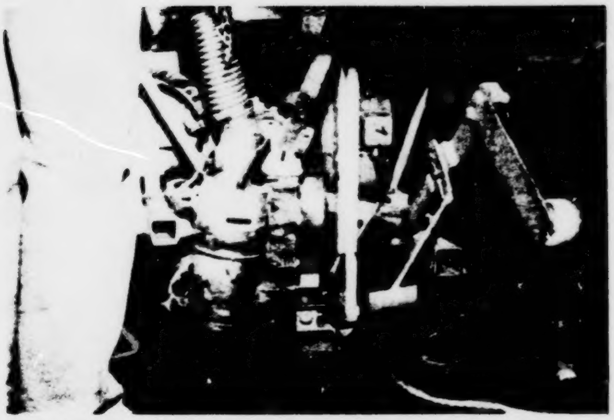
Site Joining

Site joining is the heart of a lining system. The method used must be capable of creating joints that are not a point of chemical or physical weakness in the complete lining system under varying site conditions. The patented **Schlegel®** extrusion welding process has this capability.

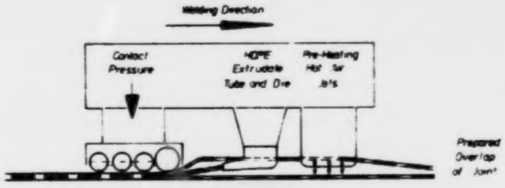
Three different types of machines are used to create homogeneous, welded joints:

1. Self-propelled automatic extrusion welder—used on level surfaces to make standard overlap joints
2. Semi-automatic extrusion welder—used on steep embankments, using a controlling winch for propulsion
3. Hand-held extrusion welder—used for detailing work, hard-to-reach areas, and repairs.

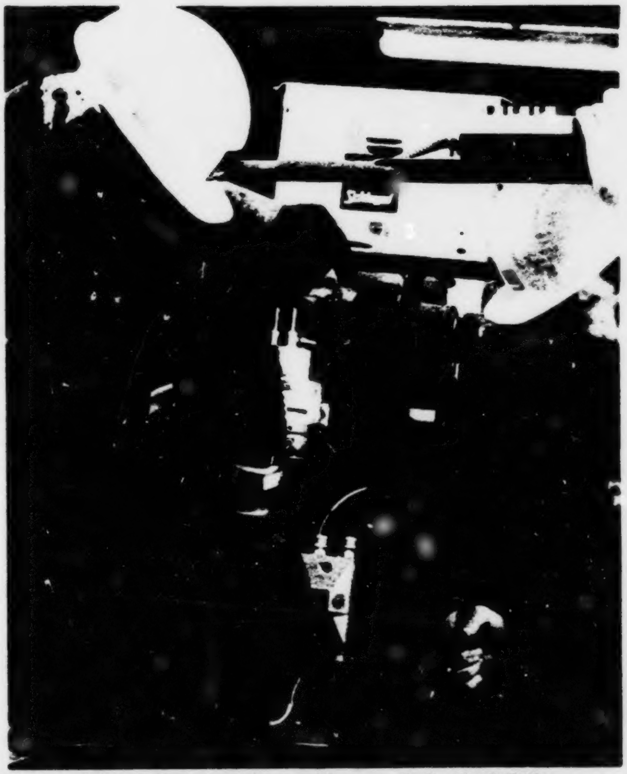
Each machine is powered from a local generator, and creates a homogeneous weld by injecting into the pre-heated overlap a molten ribbon of extrudate of exactly the same composition as the parent sheet. Immediate compression completes the seal.

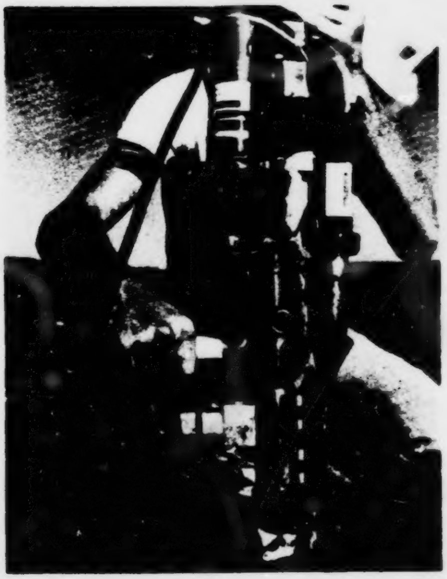


Extrusion welding maintains the strength values of the parent sheet through every inch of every seam. The joining system is also adaptable to on-site design changes or repairs.



Principle of Extrusion Welding for Site Joining





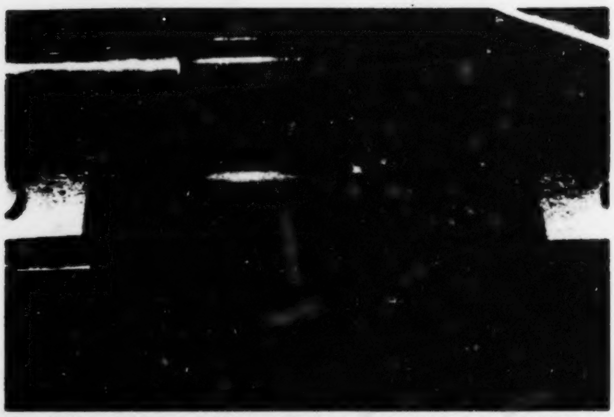
Each welding unit was engineered for use during installation of a SCHLEGEL® lining system, and will operate within narrow tolerances under varying climatic conditions.

Site Joint Testing

The joint testing systems used by Schlegel Lining Technology ensure the security of the lined area. Two specific groups of testing procedures cover individual machine performance, and the final weld quality obtained.

Pre-Welding Simulation Testing Procedures
Each day, prior to welding the liner, two pieces of sheet are joined under the same conditions as exist for the liner. The joint is then subjected to an on-site tensometer test to determine behavior under tensile loading. This test ensures optimum machine settings for the conditions, as well as providing a strict operator control.

Ultra-sonic and physical testing on site provide a combination that ensures security.



Simulation testing provides control over operator and machine performance under actual site conditions.

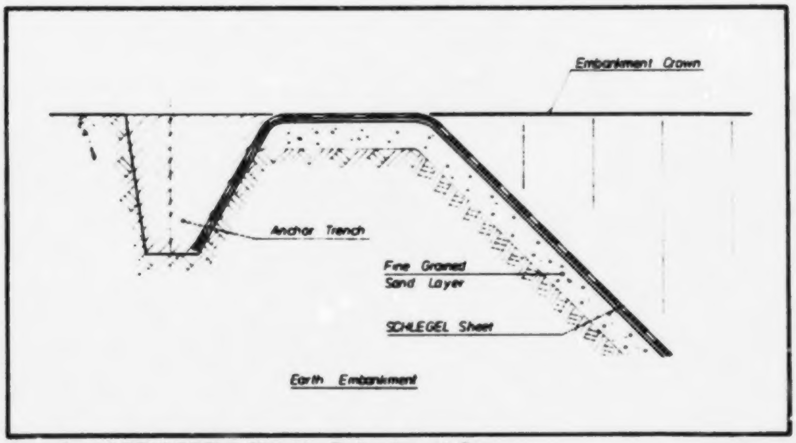
Post-Welding Testing Procedures
After the installation of the lining, joints are tested by one or more of the following methods:

1. **Ultra-sonic (non-destructive) Testing**
   A high-frequency sound wave is passed through the thickness of the joint. If any voids, foreign objects, or obstructions are detected, an audible signal notifies the operator, and the spot on the sheet is marked.
2. **Random Sampling (destructive)**
   Random samples of weld are cut from the sheet and subjected to on-site tensile testing, or to independent laboratory testing. A replacement patch must be made with this form of testing at the point where the sample is taken.

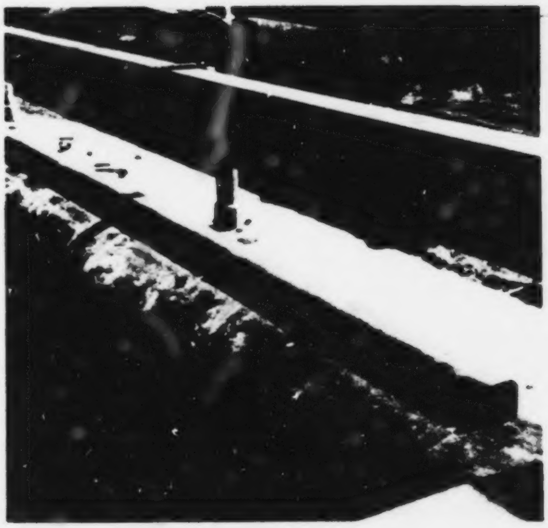
Typical Construction Details

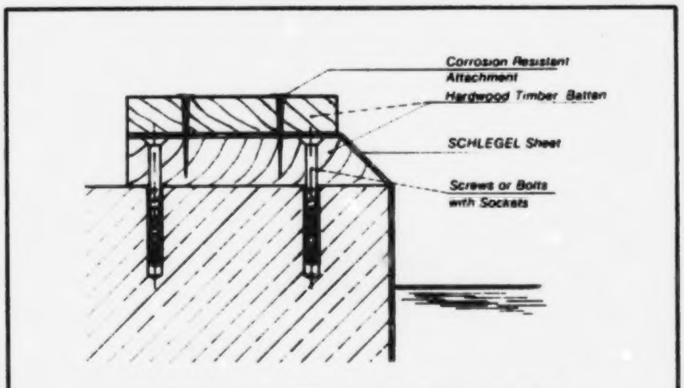
The construction details illustrated are specifically designed for compatibility with the properties of the **Schlegel®** sheet. Variations of these details may be required for different applications or site circumstances.

In chemical containment applications where HDPE pipes are used, **Schlegel** sheet is welded directly to the external surface of the pipe, providing a homogeneous joint.


Embankment Crown
Anchor Trench
Fine Grained Sand Layer
SCHLEGEL Sheet
Earth Embankment

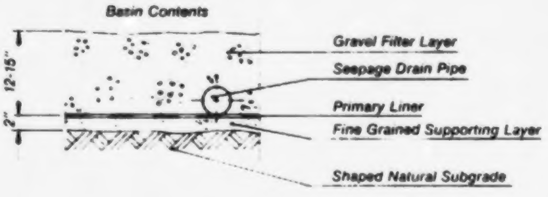
Securing of SCHLEGEL® Sheet to Embankment Crown.




Corrosion Resistant Attachment
Hardwood Timber Batten
SCHLEGEL Sheet
Screws or Bolts with Sockets

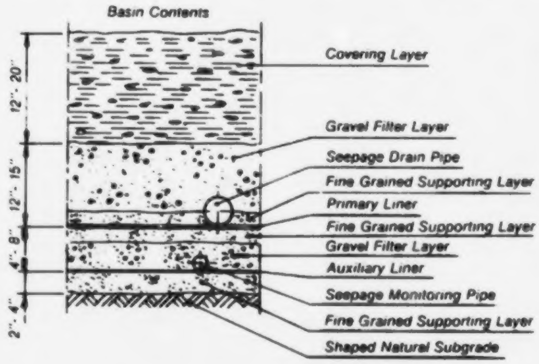
Connection of SCHLEGEL Sheet to Existing Structure

Seasoned hardwood and non-ferrous screws and bolts must be used for timber fastenings on exposed surfaces and chemical tanks.


Basin Contents
12-15"
2"
Gravel Filter Layer
Seepage Drain Pipe
Primary Liner
Fine Grained Supporting Layer
Shaped Natural Subgrade

Typical Ground Water Protection Lining System

Fig. 1


Basin Contents
12"- 20"
12"- 15"
4"- 8"
2"- 4"
Covering Layer
Gravel Filter Layer
Seepage Drain Pipe
Fine Grained Supporting Layer
Primary Liner
Fine Grained Supporting Layer
Gravel Filter Layer
Auxiliary Liner
Seepage Monitoring Pipe
Fine Grained Supporting Layer
Shaped Natural Subgrade

Maximum Design of Ground Water Protection Liner

Fig. 1A

Design of Lining System

A typical engineered lining system, e.g. for ground water protection, consists of four main components:

- Natural Subgrade
- Supporting Layer
- Synthetic Liner
- Covering Layer

To attain the impermeability, and therefore security in varying conditions, the most controllable component is the synthetic or man-made lining. This lining will dictate the engineering (and, therefore, cost of the engineering) of other components comprising the system. Figure 1A shows maximum design of a ground water protection system. This lining must therefore be substantial in its thickness to provide sufficient physical strength and operational endurance to play its part with the natural materials.

Natural Subgrade

The natural subgrade must be able to withstand high loads, both from various types of installation equipment and vehicles and from the subsequent installed system itself. Some subgrades can be used as excavated, but most require some preparatory works.

The surface of the natural subgrade should be approximately parallel to the surface of the synthetic liner. The surface need not be smooth, but larger protrusions such as large rocks and tree stumps should be removed as these can cause damage if uneven soil settlement occurs. The degree of compaction should be sufficient to ensure subgrade permanence and firmness. A typical compaction value would be 90% of the Standard Proctor density.

Supporting

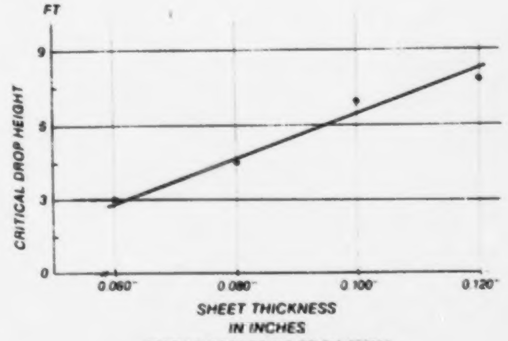
The purpose of the supporting layer is to provide a uniform contact surface for the synthetic liner, if this is not possible with the natural subgrade (i.e. rock outcrops). This layer should have good water conduction properties for drainage of local surface water, or gases. The supporting layer should consist of a sand or granular layer approximately 2-4 in. thick. Ideally the medium employed should be rounded form material with a maximum grain diameter not greater than 0.28 in. If artificial crushed material is used, the maximum grain diameter should not be greater than 0.12 in. Crushed material is generally advantageous in embankments from a soil engineering viewpoint, due to its higher angle of repose.

Synthetic Liner

The synthetic liner is the impermeable barrier between the basin contents and the surrounding ground water. It is the heart of the lining system, and its engineering design considerations are therefore of the greatest importance.

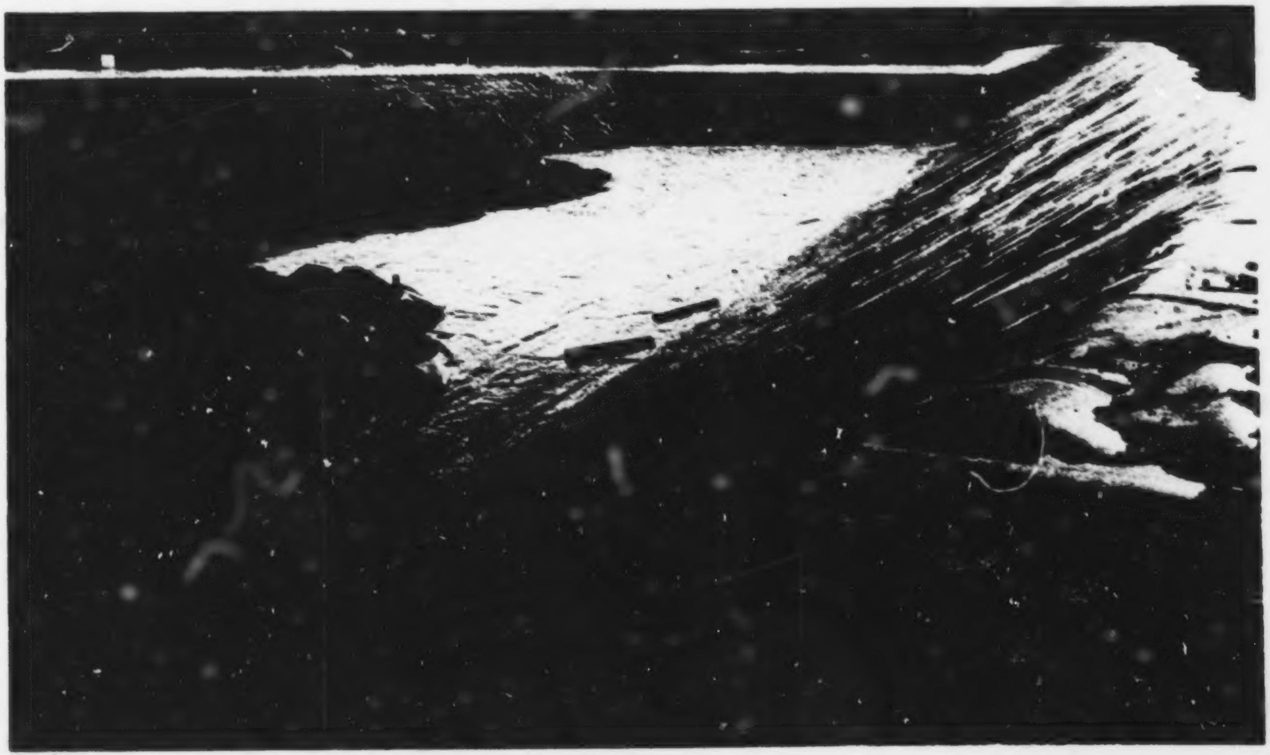
The synthetic liner must be impermeable to the contents of the basin and must have good physical strength properties to overcome uneven subgrade settlement or unexpected loading. These properties are given in the HDPE resin used for **Schlegel®** sheet production and are ensured by the high sheet thickness of 0.100" (100 mils).

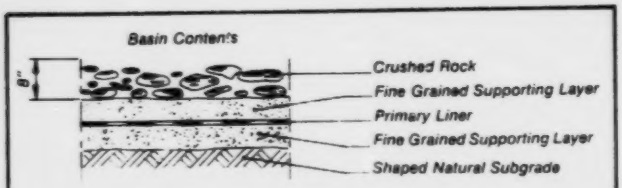
Typical puncture resistance testing results.



CRITICAL DROP HEIGHT VS THICKNESS FOR **SCHLEGEL** SHEET

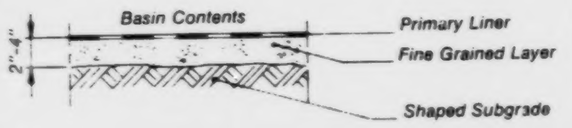
Fig. 2





Canal or River Lining System

Fig. 2a



Water Reservoir Lining System

Fig. 2b

Covering Layer

The primary requirement of the covering layer may vary with the detailed application but will provide some or all of the following functions:

(a) Distribution of point stressing to the synthetic lining;

(b) Reduction of temperature fluctuations, weathering, etc.;

(c) Filtration and drainage media to assist in minimizing effluent contained;

(d) Protection of synthetic lining for extraction of settled solids by mechanised means.

The thickness of this covering layer must be sufficient to achieve the primary requirement for the application—in general this layer should not be less than 12" in thickness. The granular size and type employed will be related to its primary requirements. In the case of drainage, where regularity of size is required, the granules should not exceed a maximum size of .87" to prevent point stressing under compaction, or operational loading. When used purely as a protection layer, variable gradings (i.e. sand and gravel), may be employed with a maximum grain size content not exceeding 1.2". If large granules are required for protection or stability under high water flow conditions this total protective layer is increased by graded thickness allowing large granules or rock formation to be used.

Alternative Systems

The four-component system described is sufficient for the majority of ground water protection applications.

If the structure to be lined is a canal or river, a different type of covering layer can be used: a sand layer topped with a crushed rock layer. This system is shown in Figure 2a. A fiber mat may be included between the two layers to prevent intermixing if required.

Reservoir lining systems do not usually require a covering layer. The basin contents serve to cover the liner and no physical protection is needed as shown in Figure 2b.

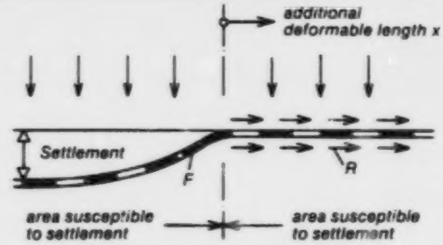
Schlegel · Determining Liner Thickness

In a given liner system, two factors can be varied to optimize site performance: the resin employed in production (described in the section entitled "Raw Material") and the liner thickness. Intuitively, it is obvious that the thicker the liner, the higher the strength properties will be. More exact data on the effect of thickness on physical properties can be illustrated by mathematical models and experimental data.

Deformation Behavior

Deformation of a synthetic liner usually occurs due to differential soil settlement from operational loading. An important property of a liner is its ability to spread such deformation over neighboring areas, spreading concentration of local deformation. This process can be simulated by the model shown in Figure 3 below. This model operates on the basis of a static equilibrium between frictional force and tensile strength with elongation occurring up to the yield point of the liner. The resultant equation for the additional deformable length x beyond the perimeter of a settlement is as follows:

$$x = \frac{\sigma_Y \cdot t}{2A \cdot \alpha}$$


additional deformable length x
Settlement
F
R
area susceptible to settlement
area susceptible to settlement

F = tensile force

F_{max} = $\sigma_Y \cdot t$

σ_Y = yield strength of liner (2800 psi for Schlegel® sheet)

t = thickness of liner (0.080" for Schlegel sheet)

R = frictional forces

R = $A \cdot \mu$

A = loading

μ = coefficient of friction between sand subgrade and liner (~0.35 for Schlegel sheet)

Σ_R = $2 \cdot R \cdot x$

x = additional deformable length

Σ_R ≤ F_{max}

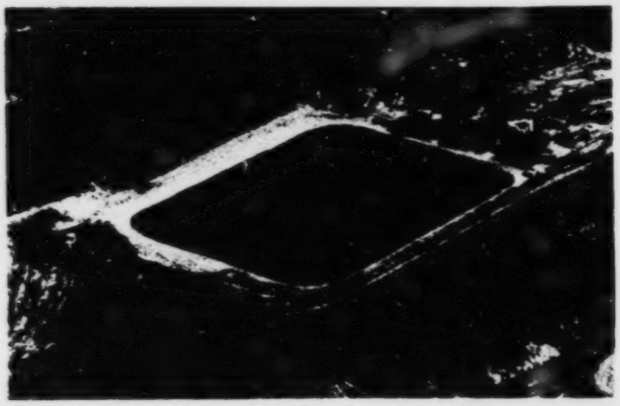
$x \cdot A \cdot 2\mu = \sigma_Y \cdot t$

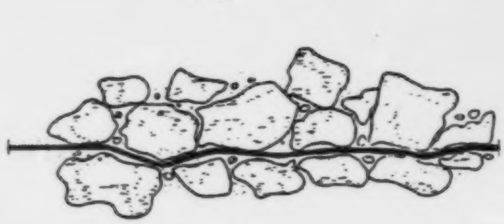
$$\boxed{x = \frac{\sigma_Y \cdot t}{A \cdot 2\mu}}$$

Fig. 3 Mathematical Model of Additional Deformable Length under Differential Settlement

The two variable factors for a given system are t, the liner thickness and α, the force transfer coefficient.

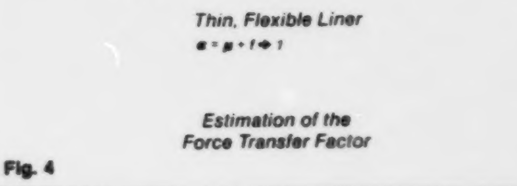
The value of the force transfer coefficient depends on the type of force transfer, as shown in Figure 4. The force transfer coefficient is the sum of the coefficient of friction μ and the forming coefficient f.





Thick, Stiff Liner

$\alpha \rightarrow \mu \qquad f \rightarrow 0$



Thin, Flexible Liner

$\alpha = \mu + f \rightarrow 1$

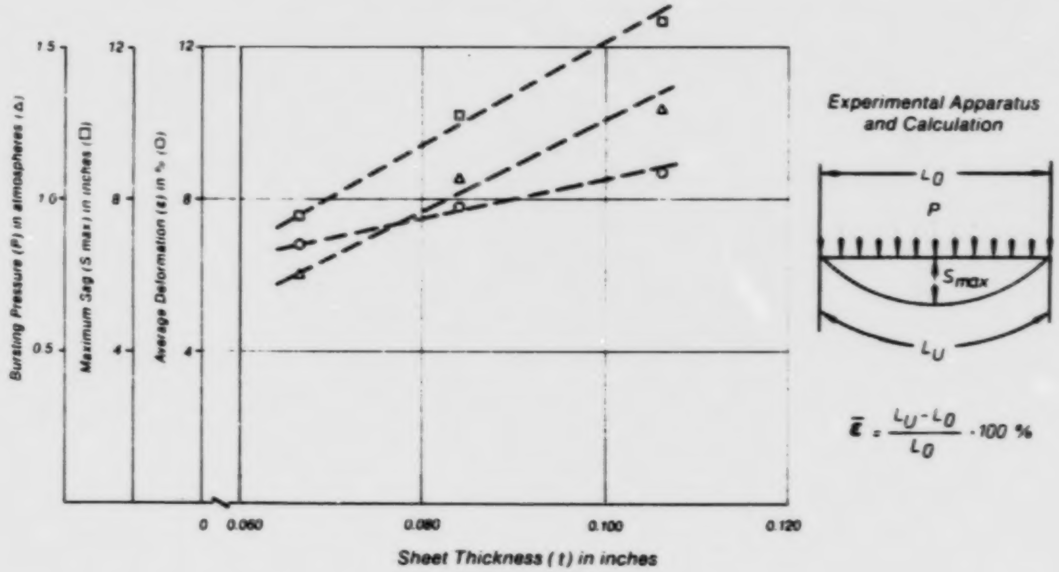
Fig. 4 Estimation of the Force Transfer Factor

As can be seen in Figure 4, a thin, flexible liner is effectively clamped in place by the upper and lower adjoining surfaces. (This is represented in the model by α approaching 1.) When this effect is pronounced, conduction of stress to neighboring zones is restricted, causing danger of local failure in the affected areas of the liner.

On the other hand, a thick liner would represent the other extreme. Ideally, f equals zero in this case, which implies that the entire force transfer is only frictional. As can be seen in the lower part of Figure 4, this enables stress to be conducted over large areas of the liner, keeping the actual local deformation low. The force transfer coefficient α is dependent on the thickness t; therefore in actuality, only the thickness t will additionally affect the deformable length x.

This additional deformable length becomes important when one considers the elongations in settlements found in field conditions.

Actual materials testing corroborates these estimates. Bursting strength testing causes multiaxial tensile stress in a liner as found in practice. In this testing, a circular liner is loaded with pressure until it bursts. Typical results of this testing for **Schlegel®** sheet are shown in Figure 5. It can be seen that the critical pressure, the depression depth and average elongation, all increase for increasing thickness. Again this only reflects liner thickness and not any effect of reduced physical properties as found in other systems, as all specimens were of **Schlegel** sheet.



Bursting Pressure, Maximum Sag and Average Deformation vs Sheet Thickness

Fig. 5

Typical biaxial tensile testing.

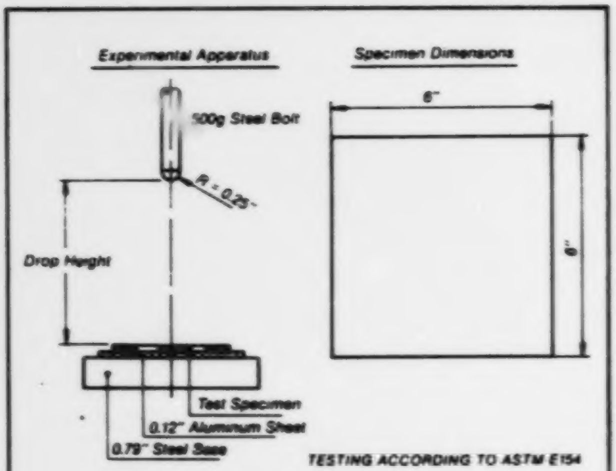
Determining Liner Thickness

Tear Resistance
Tearing in a synthetic liner is usually encountered when an area containing existing damage (e.g. small perforations, manufacturing faults etc.) is subjected to tensile stress, causing the existing damage to propagate.

Laboratory testing shows that **Schlegel®** sheet has excellent tear resistance properties as illustrated in Figure 6. The high strength of the sheet material is enhanced by the high sheet thickness. It can be seen from the graph in Figure 7 that tear resistance increases linearly with increasing thickness within the range tested.

Puncture Resistance
Puncture to a synthetic liner can be defined as compressive stress concentrated in a small area causing failure. In practice, this can occur due to falling objects, or to vehicles brought into contact with the liner creating high dynamic loadings during the installation works.

Schlegel sheet's high physical strength and thickness give it good puncture resistance properties. Puncture resistance testing has been conducted on **Schlegel** sheet as shown in Figure 8. The results shown in Figure 2 (page 5.1.2) indicate a linear relationship between puncture resistance and thickness for **Schlegel** sheet.

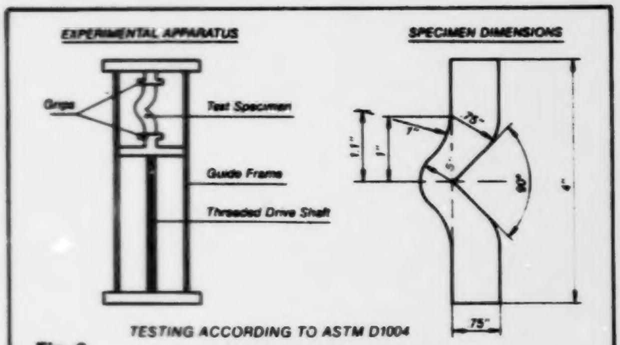

Experimental Apparatus
Specimen Dimensions
500g Steel Bolt
R = 0.25"
Drop Height
Test Specimen
0.12" Aluminum Sheet
0.79" Steel Base
6"
6"

TESTING ACCORDING TO ASTM E154

EXPERIMENTAL APPARATUS AND SPECIMEN DIMENSIONS

Fig. 8

Puncture Resistance Tests


EXPERIMENTAL APPARATUS
SPECIMEN DIMENSIONS
Grips
Test Specimen
Guide Frame
Threaded Drive Shaft
1.1"
1"
1"
.75"
.5"
90°
4"
.75"

TESTING ACCORDING TO ASTM D1004

Fig. 6 Experimental Apparatus and Specimen Dimensions

Tear Resistance Tests

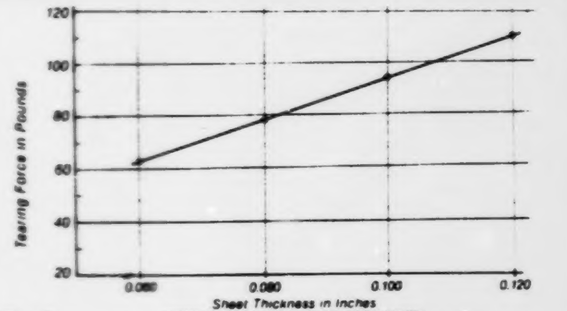


Fig. 7 TESTING ACCORDING TO ASTM D1004
TEARING FORCE VS. THICKNESS FOR **SCHLEGEL** SHEET

Typical Tear Resistance Testing

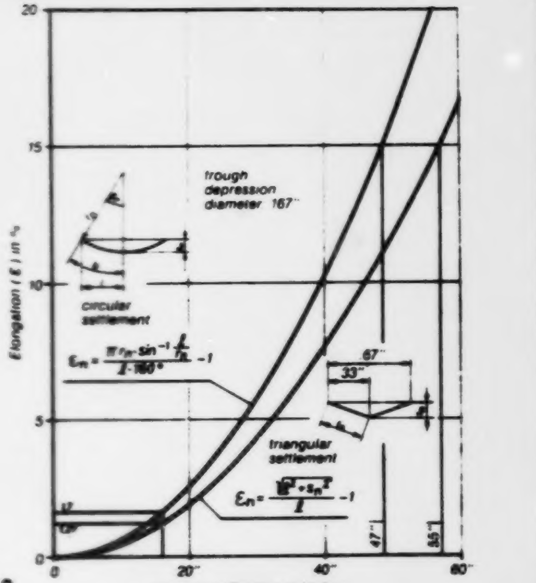


Fig. 9

Typical Liner Deformation as a Function of Settlement Depth in Center of Depression

INTEROFFICE CORRESPONDENCE

TO: Mr. R.T.Clarke

FROM: H.J.Suerbaum/Hl

DATE: March 4, 1982

SUBJECT: Cold Region Installation

I should like to give you in writing what was discussed between us on the phone on March 3, 1982. The projects in Canada are surely beautiful in size and we should find ways and techniques to overcome the risks caused by low temperature application of SCHLEGEL-Sheet.

My suggestions:

1. Use SCHLEGEL-Sheet 2,5 mm instead of 2,0 mm in this area. The reason: It's more rugged and it can be welded properly. When it comes to low temperature it is most important that there is no weak spot in the liner system. The liner tries to shrink in winter time.

   $\Delta T \times \alpha = +20°C / -45°C \times 1{,}5 \times 10^{-4}/°C = 65°C \times 1{,}5 \times 10^{-4}/°C = 1\%$ that is 1m/100m

   We cannot allow shrinkage but the design of a basin can ensure that the liner takes everywhere this 1% as stress and not that part of it has to take nothing and the rest all stress.

   The toes and the corners are the weak spots of an empty basin. Here uplifting will happen. To avoid uplifting 2 precautions are possible:

   a) The client should agree to a min. waterlevel which stays in the basin (for example 3'). That would avoid uplifting in the toe area.

   b) In the 4 corners of a basin the SCHLEGEL-Sheet should be covered. My suggestion is kind of min. 2 m thick sand or graver layer which can also operate as entry/exit ramps for the basin.

3. The toe and the corner areas should be designed with a generous radius.

   For the endfixing of the SCHLEGEL-Sheet on the crest several details should be carried out carefully.

a) **Trenchprofile**

The trenchprofile should show a slope on the basin side. The trench should be carried out in a straight line. As the sketch shows, the sand layer shall be placed on the crest and in the trench area to allow the sheet to form smoothly to the ground without edges.

b) **Welding in the trench area**

The slope sheets have to be welded together up to the very end of the sheets which are placed in the trench. This can be done by placing a plank across the trench.

4. The welding seams which connect the slope liner to the floor liner and every third or fourth slope seam should be carried out at a certain temperature. Doing so we know how the liner will react in sunshine and what kind of tensile stress it has to take in winter time.

Placing the ramps in the basin corners should be started at night also, the same I recommend for the water filling procedure.

5. Pipe penetrations and concrete structures in the slope areas are really unwanted for this kind of application. Inlets should be allowed to be placed on top of the liner, outlets in the floor but well off the toe area.

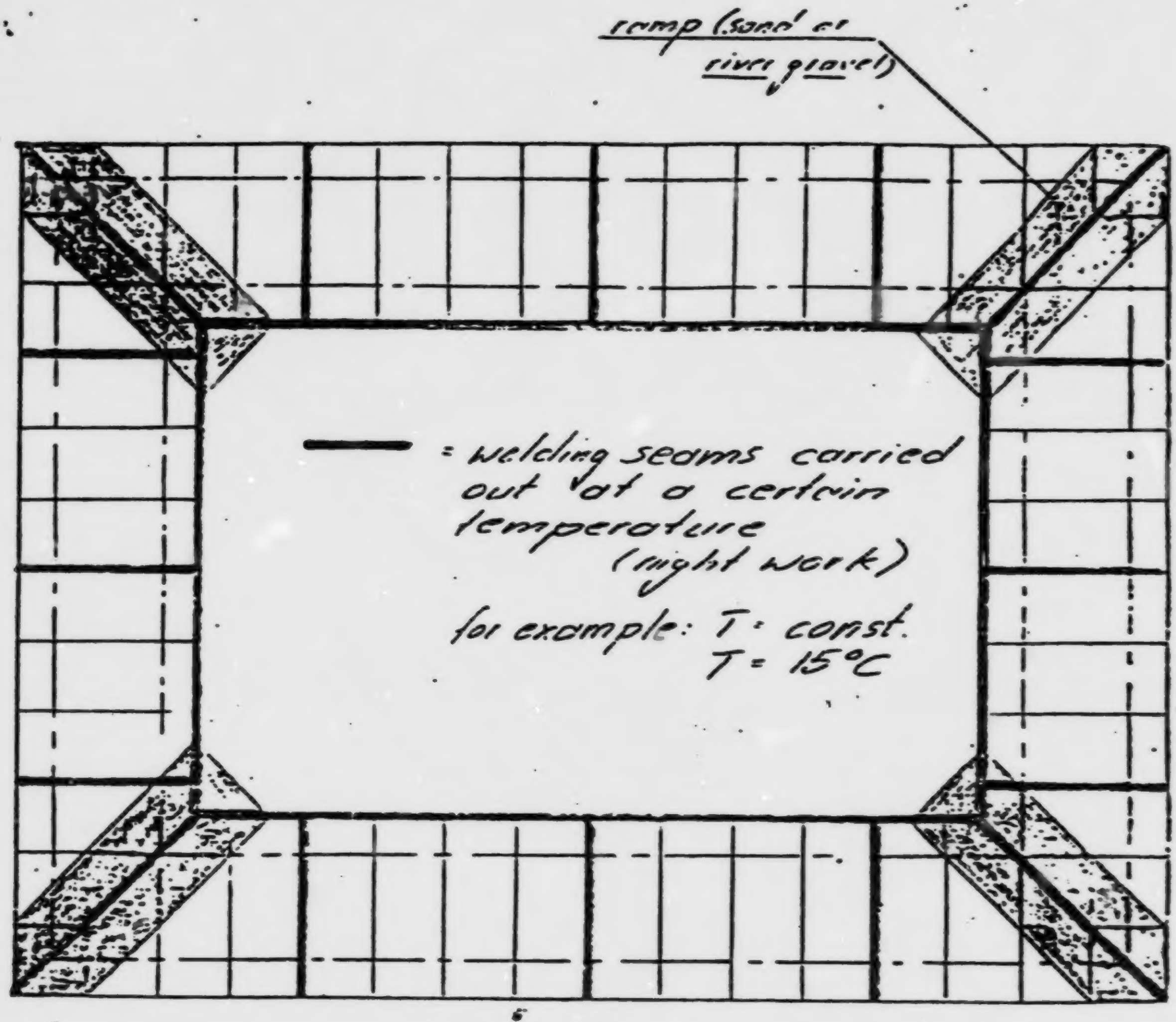
6. As far as I know we never had the opportunity to watch a SCHLEGEL-Sheet lined basin being filled with water during the winter time. 5 years ago we lined a big basin in Sar Cheshmeh, Iran. There the SCHLEGEL-Sheet is exposed to a very high rate of UV-radiation. The winters in Sar Cheshmeh (about 10.000 feet above sea level) can be as cold as - 20°C. We never heard that any damage or failure happened to the project. During installation we followed the rules I mentioned before. What we could not apply in Sar Cheshmeh was covering the corner areas of the basin with a layer of sand or river gravel.

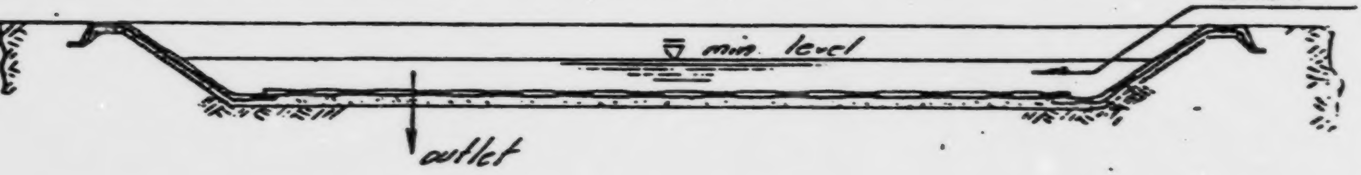
Ice may cause damages in areas where SCHLEGEL-Sheet is uplifted but apparently not in areas where SCHLEGEL-Sheet is in contact with the subsoil.

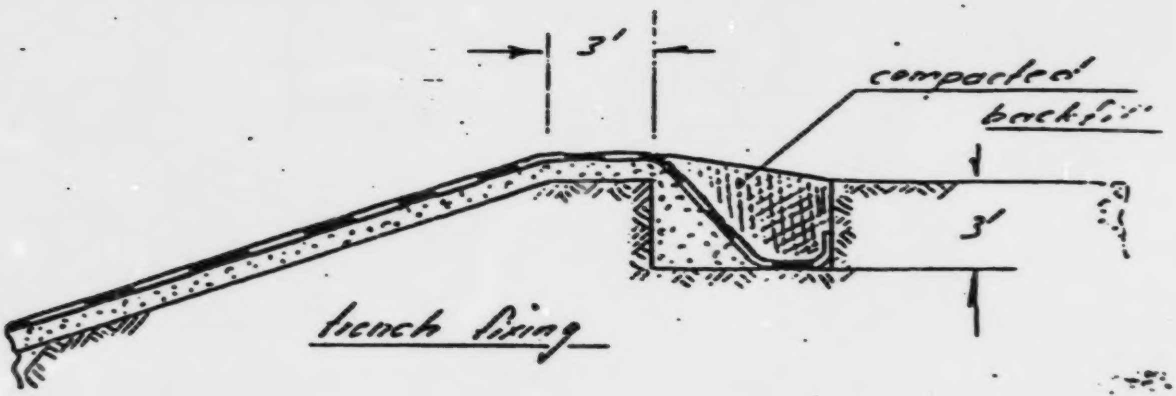
So far my experience and thoughts. When a project happens in low temperature areas please make sure that the man in charge is no cowboy.

Regards,

Hermann Suerbaum


ramp (sand or river gravel)
: welding seams carried out at a certain temperature (night work)
for example: T = const.
T = 15°C


inlet
min. level
outlet


3'
compacted backfill
3'
trench fixing

APPENDIX D-2-4

STAFF INDUSTRIES, INC.

LINING MATERIAL SELECTOR

(Confirm suitability with Staff Industries or Staff representatives.)
(See "Discussion of Materials", p. 11)

	POLYVINYL CHLORIDE (PVC)			HYPALON, Reinforced		CPE	
APPLICATION	***Standard***	***Oil***	***Reinforced***	***Industrial***	***Potable***	***Standard***	***Reinforced***
Baffles	X	X	X	X	X		X
Black Liquor	X		X	X			X
Brine Ponds	X		X	X		X^B	X
Building Waterproofing	X					X	
Canals	X		X	X	X		X
Coal Pile Liners/Covers	X	X	X	X			X
Cooling Ponds	X	X	X	X		X^B	X
Covers, Floating							
Potable water					X		
Industrial wastes			X	X			
Sewage lagoons			X	X			
Cutoff Curtains	X						
Dam & Levee Covers	X			X			X
Decorative Ponds	X			X			
Evaporation Ponds	X		X	X		X^B	X
Farm Ponds	X						
Filter Beds	X			X			X
Fire Ponds	X			X			X
Fish Ponds	X^F				X^F		
Fly Ash Ponds	X			X		X	X
Golf Course Ponds	X						
ndustrial Wastes Ponds							
Industrial wastes	X	X	X	X		X	X
Hazardous wastes	X	X	X	X		X	X
Landfills							
Municipal	X			X			
Industrial	X	X	X	X			X
Leaching Pits	X			X		X	X
Manure Storage	X						
Oil-Spill Containment		X	X			X^O	X^O
Oxidation Ponds	X	X	X	X		X	X
Paper Wastes Ponds	X			X		X	X
Recreation Ponds	X						
Reservoirs							
Industrial	X		X	X		X	X
Potable					X	X	
Sewage Lagoons							
Municipal	X			X		X	X
Industrial	X			X		X	X
Sludge drying beds	X			X		X	X
Solar Evaporation Ponds	X		X	X		X	X
Tailings Ponds	X			X		X	X
Tank Linings	X	X	X	X	X	X	X
Thickeners	X						
Waste Water	X	X	X	X	X	X	X

See specifications on pages: 7–11

B — Bottoms F — Fish grade O — Special oil

HYP-R-I

STAFF INDUSTRIES, INC. 78 Dryden Road Upper Montclair, N. J. 07043

STANDARD SPECIFICATIONS for REINFORCED HYPALON PLASTIC LININGS and COVERS*
#9210 - Industrial Grade

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a reinforced Hypalon plastic lining in the structures where shown on the drawings or directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and be subject to the terms and conditions of the contract.

02 - MATERIALS

A. General. The materials supplied under these specifications shall be first quality products designed and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The contractor shall, at the time of bidding, supply the Engineer with the name of the lining fabricator and, later, a certified test report from the sheeting producer that the sheeting meets these specifications for durable liner and cover material.

B. Description of Reinforced Hypalon Materials. Reinforced Hypalon plastic lining shall consist of widths of calendered reinforced Hypalon sheeting fabricated into large sections by STAFF INDUSTRIES, INC., Upper Montclair, N. J., 07043, by means of Hypalon-solution-bonded factory seams into a single piece or into the minimum number of large pieces to fit the facility. The reinforced Hypalon sheet shall be made by encapsulating reinforcing fabric between two sheets of 15 mil or heavier-gauge Hypalon sheeting, made from a composition of which du Pont Hypalon 45 is at least 45% by weight of the finished sheeting.

03 - MINIMUM MANUFACTURING SPECIFICATIONS

A. Unreinforced Film (Prior to Laminating). Specifications shall be as follows:

PROPERTY	*Min. Manufacturing SPECIFICATIONS*	*TEST METHOD*
1. Tensile strength	1500 psi min.	ASTM D-412
2. Elongation @ break	300% min.	ASTM D-412
3. Heat aging		ASTM D-573
Tensile strength	1500 psi min.	14 days @
Elongation @ break	150% min.	212°F
4. Water absorption	2% (wt.) max.	ASTM D-471, 7 days @ 70°F
5. Brittleness point	-45°F, no failures	ASTM D-746, Procedure B
6. Ozone resistance	No effect	ASTM D-1149, 3 ppm @ 30% strain @ 104°F, for 72 hrs.

B. The reinforced Hypalon shall be made by calender-laminating Hypalon with the above specifications on both sides of polyester fabric to give the following properties for Staff #9210 Industrial Grade sheeting:

1. Fabric count	10x10-1000 d polyester	
2. Laminate thickness, inch	.036 ± 10% & .045 ± 10%	ASTM D-751
3. Cold bend (36 mil)	-45°F, no cracks	ASTM D-2136, 1/8" mandrel
4. Tensile strength, lbs., grab method	200	ASTM D-751
5. Tear strength, lbs., tongue tear method	80	ASTM D-751
6. Puncture resistance, lbs.	180	FTM-101^{B} -2031
7. Dimensional stability		ASTM D-1204-54
2 hrs. @ 150°F	< ± 5 %	
2 hrs. @ 212°F	< ± 1 %	
8. Seam strength, factory & field, lbs.	170	ASTM D-751

*registered trade mark of du Pont

April 1980
040280-9210

04 - *FACTORY FABRICATION*

The reinforcing fabric shall be laminated between the two Hypalon sheetings so that the edges of the scrim are encapsulated 1/2" ± 1/4" so that no exposed scrim shows on the edge. Each width of reinforced Hypalon so made shall be Hypalon-solution-bonded to the next width by STAFF INDUSTRIES, INC., Upper Montclair, N. J., utilizing lap joints a minimum of 1 1/2" scrim-to-scrim and with the encapsulated edges bonded on both top and bottom edges. Seams shall be lengthwise so as to minimize the joining of cut ends of large panels. Seam strength shall be at least 170 pounds by ASTM D751. The lining shall be accordion-folded into heavy cardboard boxes or wooden boxes, for shipping purposes.

05 - *INSTALLATION OF HYPALON LINING*

A. General. The Hypalon lining shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets, and other projections through the lining. Any portion of lining damaged during installation by any cause shall be removed or repaired by using an additional piece of lining, as specified hereinafter.

1. Field Joints. Lap joints shall be used to seal factory-fabricated linings of reinforced Hypalon together in the field. All field joints between sections of Hypalon lining shall be made on a supporting smooth surface such as a board and, unless the weather is warm and the sun shining brightly, heat guns shall be used to make the sealing temperature at least 100°F. Field seams shall be rolled during heating to effect a satisfactory bond of full strength. The lap joints shall be formed by lapping the edges of pieces a minimum of 1 1/2" scrim-to-scrim. The contact surfaces of the pieces shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials. Sufficient STAFF Hypalon-to-Hypalon bonding solution shall be applied to both contact surfaces in the joint area and the two surfaces pressed together and rolled. Any wrinkles shall be smoothed out and any cut edges of the reinforced Hypalon shall be sealed with a flood coat of Hypalon solution to prevent wicking.

2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of Hypalon to concrete shall be made with STAFF Hypalon-to-concrete adhesive and mechanical fasteners. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cement joint shall be 4 inches. For all shapes like pipe boots that require extensibility, unreinforced Hypalon shall be used.

3. Repairs to Hypalon. Any necessary repairs to the Hypalon shall be patched with the lining material itself and STAFF Hypalon-to-Hypalon bonding solution The bonding solution shall be applied to the contact surfaces of both the patch and lining to be repaired and the two surfaces pressed together immediately, heated, and rolled. Any wrinkles shall be smoothed out.

4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of Hypalon of the proper size.

B. Technical Assistance. A representative of the company furnishing the plastic lining shall be present during the entire installation procedure and shall provide technical assistance for the installation of the lining.

STAFF INDUSTRIES, INC. 78 Dryden Road Upper Montclair, N. J. 07043

STANDARD SPECIFICATIONS for REINFORCED HYPALON PLASTIC LININGS and COVERS*
#8210 - Potable Grade

01 - GENERAL REQUIREMENTS

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2. Elongation @ break	250% min.	ASTM D-412
3. Heat aging		ASTM D-573
Tensile strength	1000 psi min.	14 days @
Elongation @ break	150% min.	212°F
4. Water absorption	5% (wt.) max.	ASTM D-471, 7 days @ 70°
5. Brittleness point	-45°F, no failures	ASTM D-746, Procedure B
6. Ozone resistance	No effect	ASTM D-1149, 3 ppm @ 30 strain @ 104°F, for 72 hr

B. The reinforced Hypalon shall be made by calender-laminating Hypalon with the above specifications on both sides of polyester fabric to give the following properties for Staff #8210 Potable Grade sheeting:

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2. Laminate thickness, inch	.036 + 10% & .045 ± 10%	ASTM D-751
3. Cold bend (36 mil)	-45°F, no cracks	ASTM D-2136, 1/8" mandr
4. Tensile strength, lbs., grab method	200	ASTM D-751
5. Tear strength, lbs., tongue tear method	80	ASTM D-751
6. Puncture resistance, lbs.	180	FTM-101^{B} -2031
7. Dimensional stability		ASTM D-1204-54
2 hrs. @ 150°F	≤+0.5%	
2 hrs. @ 212°F	≤+1%	
8. Seam strength, factory & field, lbs.	170	ASTM D-751

April 1980
040180-8210

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2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of Hypalon to concrete shall be made with STAFF Hypalon-to-concrete adhesive and mechanical fasteners. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cement joint shall be 4 inches. For all shapes like pipe boots that require extensibility, unreinforced Hypalon shall be used.

3. Repairs to Hypalon. Any necessary repairs to the Hypalon shall be patched with the lining material itself and STAFF Hypalon-to-Hypalon bonding solution The bonding solution shall be applied to the contact surfaces of both the patch and lining to be repaired and the two surfaces pressed together immediately, heated, and rolled. Any wrinkles shall be smoothed out.

4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of Hypalon of the proper size.

B. Technical Assistance. A representative of the company furnishing the plastic lining shall be present during the entire installation procedure and shall provide technical assistance for the installation of the lining.

STAFF INDUSTRIES, INC. 78 Dryden Road Upper Montclair, N. J. 07043

POLYVINYL CHLORIDE PLASTIC LININGS

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a polyvinyl chloride (PVC) plastic lining in the facilities where shown on the drawings or as directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and shall be subject to the terms and conditions of the contract.

02 - MATERIALS

A. General. The materials supplied under these specifications shall be first quality products designed and manufactured specifically for the purposes of this work and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The Contractor shall, at the time of bidding, supply the Engineer with the name of the lining fabricator and, later, a certified test report from the sheeting producer that the sheeting meets these specifications for durable lining material.

B. Description of PVC Materials. PVC plastic lining shall consist of widths of calendered PVC sheeting fabricated into large sections by STAFF INDUSTRIES, INC., Upper Montclair, N. J., 07043, by means of PVC-solution-bonded factory seams into a single piece or into the minimum number of large pieces required to fit the facility.

03 - MINIMUM MANUFACTURING SPECIFICATIONS

A. The PVC materials shall conform to the following minimum manufacturing specifications:

PROPERTY	*Min. Mfg. SPECIFICATIONS*	*TEST METHOD*
Thickness	Specified ± 10%	
Specific gravity	1.24 - 1.30	
Tensile strength, psi, min.	2300	ASTM D882-B
Elongation, % min.	300	ASTM D882-B
100% modulus, psi	1000 - 1600	ASTM D882-B
Graves tear, lbs./in., min.	300	ASTM D1004
Water extraction, % max.	0.35	ASTM D1239
Volatility, % max.	0.7	ASTM D1203
Impact cold crack, °F.	-20	ASTM 1790
Dimensional stability, % max., (100°C - 15 minutes)	5	
Solvent-bonded seam strength, % of tensile, min.	80	
Resistance to burial		Formulation shall have passed USBR test (specially formulated for resistance to microbiological attack)
Alkali resistances		Passes Corps of Eng. CRD-572-61
Color - Gray (Std.) (Black or other colors on special order)		
Factory seals - 3/4" solution-bonded		

B. PVC polyvinyl chloride materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for use in hydraulic facilities. Reprocessed material shall not be used. It shall be dark gray in color and produced in a standard minimum width of 61 inches. Thickness shall be as shown on the project drawings. Certified test results showing that the sheeting meets the specifications shall be supplied.

04 - *FACTORY FABRICATION*

Individual widths of PVC materials shall be fabricated into large sections by PVC-solution-bonding by STAFF INDUSTRIES, INC., Upper Montclair, N. J., into a single piece or into the minimum number of pieces, up to 100 feet wide, as are required to fit the facility. Lap joints with a minimum joint width of 3/4 inch shall be used. After fabrication, the lining shall be accordion-folded in both directions into heavy cardboard boxes or wooden boxes for shipping purposes.

05 - *INSTALLATION OF PVC LINING*

A. General. The PVC lining shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining, in accordance with details shown on drawings submitted by the Contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets, and other projections through the lining. Any portion of lining damaged during installation by any cause shall be removed or repaired by using an additional piece of lining, as specified hereinafter.

1. Field Joints. Lap joints of the same kind as used in the factory shall be used to seal factory-fabricated pieces of PVC together in the field. Lap joints shall be formed by lapping the edges of pieces a minimum of 2 inches. The contact surfaces of the pieces shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials. Sufficient STAFF vinyl-to-vinyl bonding solution shall be applied to both contact surfaces in the joint area and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of PVC to concrete shall be made with STAFF vinyl-to-concrete adhesive. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cemented joint shall be 8 inches. Where shown on the drawings, batten strips shall be used to reinforce the adhesive bond. Any pipe boots required shall be made of the same material.

3. Repairs to PVC. Any necessary repairs to the PVC shall be patched with the lining material itself and STAFF vinyl-to-vinyl bonding solution. The bonding solution shall be applied to the contact surfaces of both the patch and lining to be repaired and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC of the proper size.

B. Technical Assistance. A representative of the company furnishing the plastic lining shall be present during the entire installation procedure and shall provide technical assistance for the installation of the lining.

STAFF INDUSTRIES, INC. 78 Dryden Road Upper Montclair, N. J. 07043 CPE

STANDARD SPECIFICATIONS for CHLORINATED POLYETHYLENE PLASTIC LININGS and COVERS

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a chlorinated polyethylene (CPE) plastic lining in the facilities where shown in the drawings or as directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and shall be subject to the terms and conditions of the contract.

02 - MATERIALS

A. General. The materials supplied under these specifications shall be first quality products designed and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The contractor shall, at the time of bidding, supply the Engineer with the name of the lining fabricator and, later, a certified test report from the sheeting producer that the sheeting meets these specifications for durable lining and cover material.

B. Description of Chlorinated Polyethylene (CPE) Materials. CPE plastic lining shall consist of widths of calendered CPE sheeting fabricated into large sections by STAFF INDUSTRIES, INC., Upper Montclair, N. J., 07043, by means of CPE-solution-bonded factory seams into a single piece or into the minimum number of large pieces required to fit the facility.

03 - MINIMUM MANUFACTURING SPECIFICATIONS

A. The CPE materials shall conform to the following minimum manufacturing specifications:

PROPERTY	Min. Manufacturing SPECIFICATIONS	TEST METHOD
1. Color	Gray to black	- - - -
2. Thickness	Specified ± 5%	ASTM D1593
3. Specific gravity, min.	1.29	ASTM D792
4. Water extraction, % loss, max.	.35%	ASTM D1239
5. Volatility, % max.	.50%	ASTM D1203-A
6. Cold crack	-25°F	ASTM D1790
7. Tensile strength, psi, min.	Long. - 1850 Trans. - 1500	ASTM D882 Method A
8. 100% modulus, psi, min.	Long. - 700 Trans. - 450	ASTM D882 Method A
9. Ultimate elongation, % min.	Long. - 325% Trans. - 350%	ASTM D882 Method A
10. Graves tear, lbs./in., min.	Long. - 250 Trans. - 250	ASTM D1004
11. Dimensional stability, % max.	Long. - 212°F - 10% Trans. - 158°F - 3%	ASTM D1204
12. CPE, as percent of total polymer, min.	50%	Manufacturer's certification
13. Factory seals - 3/4" solution-bonded		- - - -
14. Factory seals, % of tensile	80%	- - - -

B. CPE chlorinated polyethylene materials shall be manufactured from domestic virgin chlorinated polyethylene resin and specifically compounded for use in hydraulic facilities. Reprocessed materials shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of 61 inches. Thickness shall be as shown on the project drawings. Certified test results showing that the sheeting meets the specifications shall be supplied.

04 - *FACTORY FABRICATION*

Individual widths of CPE materials shall be fabricated into large sections by CPE-solution-bonding by STAFF INDUSTRIES, Inc., Upper Montclair, N. J., 07043, into a single piece, or into the minimum number of pieces, up to 100 feet wide, as required to fit the facility. Lap joints with a minimum joint of 3/4 inch shall be used. After fabrication, the lining shall be accordion-folded in both directions into heavy cardboard boxes or wooden boxes, for shipping purposes.

05 - *INSTALLATION OF CPE LINING*

A. General. The CPE lining shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets, and other projections through the lining. Any portion of lining damaged during installation by any cause shall be removed or repaired by using an additional piece of lining, as specified hereinafter.

1. Field Joints. Lap joints shall be used to seal factory-fabricated pieces of CPE together in the field. Lap joints shall be formed by lapping the edges of pieces a minimum of 2 inches. The contact surfaces of the pieces shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials. Sufficient STAFF CPE-to-CPE bonding solution shall be applied to both contact surfaces in the joint area and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of CPE to concrete shall be made with STAFF CPE-to-concrete adhesive and mechanical fasteners. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cemented joint shall be 4 inches. Where shown on the drawings, batten strips shall be used to reinforce the adhesive bond. Any pipe boots required shall be made of the same material.

3. Repairs to CPE. Any necessary repairs to the CPE shall be patched with the lining material itself and STAFF CPE-to-CPE bonding solution. The bonding solution shall be applied to the contact surfaces of both the patch and lining area to be repaired and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of CPE of the proper size.

B. Technical Assistance. A representative of the company furnishing the plastic lining shall be present during the entire installation procedure and shall provide technical assistance for the installation of the lining.

STAFF INDUSTRIES, INC. 78 DRYDEN ROAD Upper Montclair, N. J. 07043

STANDARD SPECIFICATIONS for OIL-RESISTANT CHLORINATED POLYETHYLENE PLASTIC LININGS

01 - *GENERAL REQUIREMENTS*

The work covered by these specifications consists of installing an oil-resistant chlorinated polyethylene (CPE) plastic lining in the facilities where shown in the drawing or as directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and shall be subject to the terms and conditions of the contract.

02 - *MATERIALS*

A. General. The materials supplied under these specifications shall be first quality products designed and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The contractor shall, at the time of bidding, supply the Engineer with the name of the lining fabricator and, later, a certified test report from the sheeting producer that the sheeting meets these specifications for durable lining and cover material.

B. Description of Oil-resistant Chlorinated Polyethylene (CPE) Materials. Oil-resistant CPE plastic sheeting shall consist of widths of calendered CPE sheeting fabricated into large sections by STAFF INDUSTRIES, INC., Upper Montclair, N. J., 07043, by means of CPE-solution-bonded factory seams into a single piece or into the minimum number of large pieces required to fit the facility.

03 - *MINIMUM MANUFACTURING SPECIFICATIONS*

A. The oil-resistant CPE materials shall conform to the following minimum manufacturing specifications:

PROPERTY	*Min. Manufacturing SPECIFICATIONS*	*TEST METHOD*
1. Color	Black	- - - -
2. Thickness	30 mil, ± 10%	- - - -
3. Volatility, % max.	.40%	ASTM D1203-A
4. Cold crack	-25°F	ASTM D2136 1/8" mandrel, 4 hrs.
5. Tensile strength, psi, min.	Long. - 1500 Trans. - 1400	ASTM D412
6. 100% modulus, psi, min.	Long. - 700 Trans. - 500	ASTM D412
7. Ultimate elongation, % min.	Long. - 400% Trans. - 400%	ASTM D412
8. Graves tear, lbs./in., min.	Long. - 225 Trans. - 200	ASTM D1004 Tear die "C"
9. Dimensional stability, % max.	± 10%	ASTM D1204 @212°F, 15 Min.
10. Ozone resistance	Pass	ASTM D1149, 3 PPM @ 30% strain @ 104°F
11. Oil resistance ASTM No. 3 Oil Max. % weight gain	35%	ASTM D471 Immersion method 151 days @ 158°F
12. Resistance to soil burial - % change in original value		ASTM D3083 120-day soil burial
a. Tensile strength	- 5%	
b. Elongation at break	-20%	
c. Modulus at 100% elongation	+10%	
13. Factory seals - 3/4" solution-bonded		
14. Factory seals, % of tensile	80%	
15. CPE, as percent of total polymer, min.	50%	Mfr.'s certification

B. CPE chlorinated polyethylene materials shall be manufactured from domestic virgin chlorinated polyethylene resin and specifically compounded for use in hydraulic facilities. Reprocessed materials shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of 61 inches. Thickness shall be as shown on the project drawings. Certified test results showing that the sheeting meets the specifications shall be supplied.

04 - *FACTORY FABRICATION*

Individual widths of CPE materials shall be fabricated into large sections by CPE-solution-bonding by STAFF INDUSTRIES, Inc., Upper Montclair, N. J., 07043, into a single piece, or into the minimum number of pieces, up to 100 feet wide, as required to fit the facility. Lap joints with a minimum joint of 3/4 inch shall be used. After fabrication, the lining shall be accordion-folded in both directions into heavy cardboard boxes or wooden boxes, for shipping purposes.

05 - *INSTALLATION OF CPE LINING*

A. General. The CPE lining shall be placed over the prepared surfaces to be lined in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets, and other projections through the lining. Any portion of lining damaged during installation by any cause shall be removed or repaired by using an additional piece of lining, as specified hereinafter.

1. Field Joints. Lap joints shall be used to seal factory-fabricated pieces of CPE together in the field. Lap joints shall be formed by lapping the edges of pieces a minimum of 2 inches. The contact surfaces of the pieces shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials. Sufficient STAFF CPE-to-CPE bonding solution shall be applied to both contact surfaces in the joint area and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

2. Joints to Structures. All curing compounds and coatings shall be completely removed from the joint area. Joining of CPE to concrete shall be made with STAFF CPE-to-concrete adhesive and mechanical fasteners. Unless otherwise shown on the drawings, the minimum width of concrete shelf provided for the cemented joint shall be 4 inches. Where shown on the drawings, batten strips shall be used to reinforce the adhesive bond. Any pipe boots required shall be made of the same material.

3. Repairs to CPE. Any necessary repairs to the CPE shall be patched with the lining material itself and STAFF CPE-to-CPE bonding solution. The bonding solution shall be applied to the contact surfaces of both the patch and lining area to be repaired and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. Quality of Workmanship. All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects, or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of CPE of the proper size.

B. Technical Assistance. A representative of the company furnishing the plastic lining shall be present during the entire installation procedure and shall provide technical assistance for the installation of the lining.

STAFF INDUSTRIES INC.   240 Chene Street · Detroit, Michigan 48207 · Telephone (313) 259-1820

GENERAL INSTRUCTIONS FOR INSTALLATION of STAFF LINERS FOR PREVENTING SEEPAGE from PONDS, RESERVOIRS, CANALS, LAGOONS, etc.

Staff seepage prevention liners are made from tough, impermeable elastomeric sheeting, both reinforced and unreinforced specially compounded for long life when properly installed. Liner sections are fabricated up to widths of 110 feet by lengths up to weights of 5500 pounds, in various gauges. Bonding solvent is supplied for joining sections in the field where it is necessary to cover wider areas.

We recommend that all liners for ponds, reservoirs, lagoons, etc., be covered with earth for mechanical protection from animals, men, and weather. However, where necessary, and when they can be properly protected, lining materials with superior outdoor durability may be used as exposed membranes.

Staff Industries fabricates large liners for use in structures designed and constructed by others. The following shall serve as guidelines for the use of Staff seepage prevention liners.

1. SITE PREPARATION

The liner sections as supplied by Staff Industries are impermeable to water and gas. (For special instructions regarding high water table and gassy areas, see #2, below.) All sharp sticks, stones, and trash should be removed from the bottoms and sides of the installation, or covered with fine soil. Areas containing nut grass and quack grass should be sterilized. Preferably, the area to be covered should be rolled to effect compaction and smoothing so as to reduce local stresses on the membrane. At all times care should be taken to prevent puncturing of the liner during installation and use. A perimeter trench 8 to 12 inches square, above the waterline, is generally used for anchoring the membrane. (See sketches on reverse side.) Note minor changes.

2. HIGH WATER TABLE AND GASSY AREAS

If liners are installed over decomposing materials such as organic wastes, bogs, etc., or in areas of fluctuating water tables which "pump" air, bubbles can develop and come to the surface. They will be unable to escape because of the impermeability of the lining to water and gas and the fact that, under water, the liner has very little weight. Where such conditions might exist, special precautions should be incorporated in the design to allow venting of such gas to the sides by sloping bottoms and a layer of gas-permeable soils directly under the liner. Also, it is strongly recommended that the liner be covered on the bottom to provide weight to aid in gas removal, in addition to other possible venting methods.

3. INSTALLATION OF LININGS

Linings are supplied to projects in large, prefabricated sections, made to order, up to 110 feet wide and several hundred feet long, and weighing up to about 5500 pounds. Linings are shipped on pallets, accordion-folded in both directions for easy opening by extending the folded strip first lengthwise, using a forklift, loader, or truck. Then, with a group of men, they are opened widthwise to cover the area of the section. If areas to be impermeabilized are larger than a single piece will cover, sections can be solvent-sealed in the field to cover any area, regardless of size.

For joining two panels tgether, a long smooth work surface is recommended as a 1" x 10" x 20 ft. board is particularly suitable and can be used directly on dry ground or on supports above wet ground. The board should be drilled with a 1/2 inch hole at one end and this end should be sanded boatlike. A rope inserted through the bottom and a knot tied in the top allows the board to be pulled along as seaming is completed for the length of the board. We advise using the equivalent of a coffee can filled with about 2-3 inches of adhesive and a 2" bristle brush. This lessens the danger of an inadvertent spill. After positioning the to be joined panels lengthwise we normally start in the center placing the board in the center of a 2 to 4" overlap. Using a brush remove all sand from area adjacent to rurfaces to be joined (a wet rag might also be necessary). Using a consistent overlap, place positioning weights on both ends and in center. Lift top flap enough to insert wet brush and wet both surfaces for about 18 inches. Rub lightly at first then apply more rag pressure. Keep moving along removing center weight as you go by. Stop about 2 ft. from end of board and pull board ahead. Repeat procedure. Always have sheet perfectly in line before starting gluing. If sheets to be glued appear to "fan" out pull glued sheet back toward where you started gluing and it will straighten out. "Fish mouths" are not allowed or necessary.

After the seam is completed, the bonding solvent will have bonded the sections sufficiently so that the newly added section can be opened to its full width and another section positioned and bonded. Shear strength develops in 5 to 15 minutes, but peel strength requires several days for solvent dissipation. Seams should be carefully inspected, after a half hour or more, to detect and reseal any voids in the seam.

Refer to seaming instructions on the label of the adhesive container.

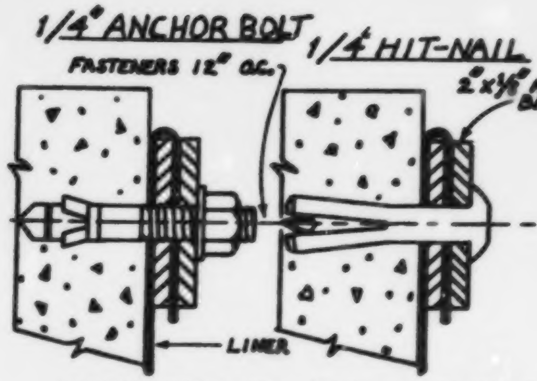
4. OBSTRUCTION SEALING

For sealing around connections, walkways, etc., several techniques are used. Some of which are shown graphically on the back side of this sheet. Around pipes we recommend the customer purchase "boots" custom made at Staff Industries factory.

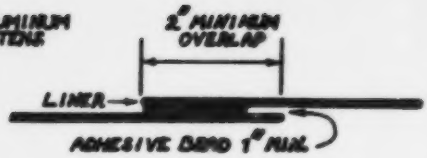
5. COVERING OF LINERS

To prevent damage to the sheeting, it is recommended that all lining surfaces be covered with earth, if possible. For side slopes, free-draining earth should be topped with erosion-resistant material such as gravel. In order to retain soil and gravel cover on the sides, a slope not steeper than 3:1 is necessary. Covering of heavier membranes which will not be subject to mechanical damage and vandalism can be by water only, if desired and gas development under the lining will not take place. A water layer will prevent damaging effects of heat to the liner as well as provide protection. Equipment used in covering the sides and bottoms of lined structures can be clamshells, front-end loaders, bulldozers, dump trucks, elevating graders, carryalls, graders, etc. Though liners are tough, equipment should not be driven directly on them, unless it is tested and proved on the job site that damage will not result. Even then, careful supervision should be provided.

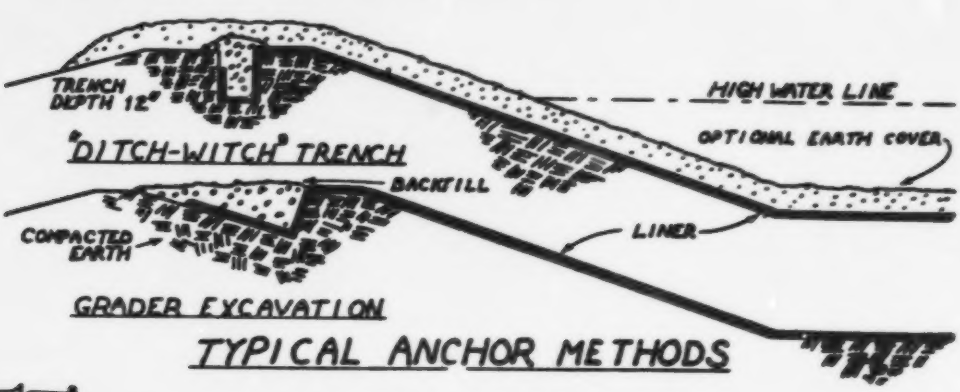
Staff Industries assumes no liability for the design or use of its membranes. No representative has authority to make any representation, promise, or agreement to the contrary.


1/4" ANCHOR BOLT
1/4" HIT-NAIL
FASTENERS 12" O.C.
2" x 1/8" ALUMINUM BATTENS
LINER

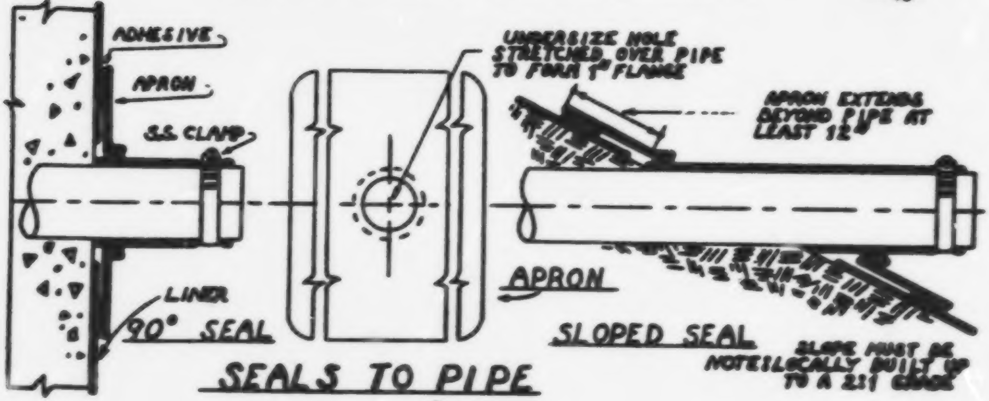
ANCHORING TO CONCRETE


2" MINIMUM OVERLAP
LINER
ADHESIVE BEAD 1" MIN.

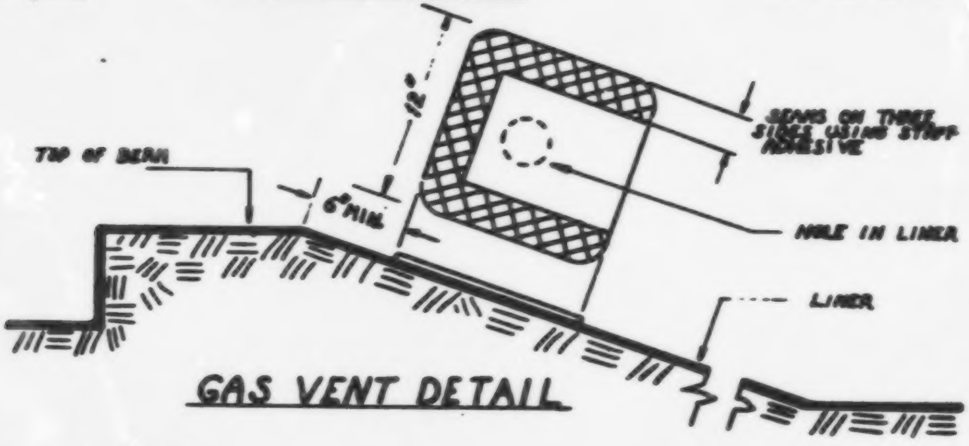
TYPICAL LAP JOINT


TRENCH DEPTH 12"
"DITCH-WITCH" TRENCH
HIGH WATER LINE
OPTIONAL EARTH COVER
BACKFILL
COMPACTED EARTH
LINER
GRADER EXCAVATION

TYPICAL ANCHOR METHODS


ADHESIVE
APRON
S.S. CLAMP
LINER
90° SEAL
UNDERSIZE HOLE STRETCHED OVER PIPE TO FORM 1" FLANGE
APRON
APRON EXTENDS BEYOND PIPE AT LEAST 12"
SLOPED SEAL
NOTE: SLOPE MUST BE LOCALLY BUILT UP TO A 2:1 GRADE

SEALS TO PIPE


TOP OF BERM
12"
6" MIN.
SEAMS ON THREE SIDES USING STAFF ADHESIVE
HOLE IN LINER
LINER

GAS VENT DETAIL

Main Sales Office:

Staff Industries Inc.
240 Chene Street
Detroit, Michigan 48207
(313) 259-1820
(800) 526-1368

Representatives
throughout the
United States

Write or phone Staff Industries for further information on our materials or assistance on your application.

Printed in U.S.A.

STAFF INDUSTRIES, INC.
78 Dryden Road
Upper Montclair, N. J. 07043
201-744-5367

STANDARD SPECIFICATIONS

PREPARATION OF SUPPORTING SURFACE

01 - PREPARATION OF SUPPORTING SURFACES

A. Preparation of Earth Subgrade. The surface of the subgrade shall be prepared by excavating and trimming the earth to elevations and sections as shown on the drawings. The prepared subgrade shall be free from loose earth, rock, cobbles, rubbish or other foreign materials. The surface of the completed subgrade shall be smooth, uniform and free from sudden changes in grade.

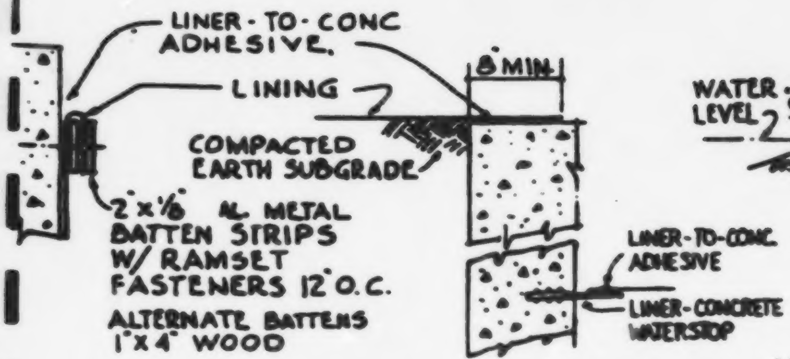
1. Additional Excavation and Backfill. As directed by the Engineer, in the lining area where gravelly materials containing large cobbles or boulders exist, these materials shall be excavated to a depth of a minimum of 3 inches and the areas backfilled and compacted to grade with selected and approved materials.

2. Preparation of Subgrade. Before final rolling and compaction, the entire subgrade shall be freed of abrupt breaks, rock, cobbles, boulders, debris and other foreign materials and shall be approved by the Engineer for installation of the lining.

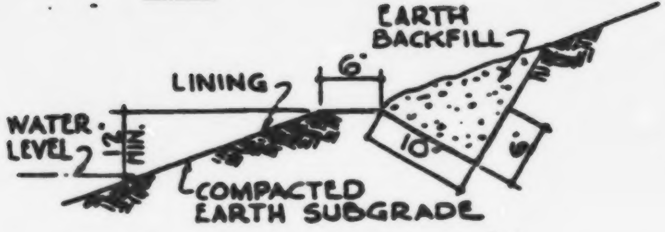
3. Rolling and Compaction of Subgrade. Compaction of the earth subgrade shall be accomplished with a vibrating roller or a steel wheel roller weighing not less than 50 pounds per linear inch of drum width. Two coverages by the roller shall be required. Areas not accessible to the roller shall be compacted by approved mechanical or hand tampers.

4. Maintenance of Subgrade. The earth subgrade shall be maintained in a smooth, uniform and compacted condition during installation of the lining.

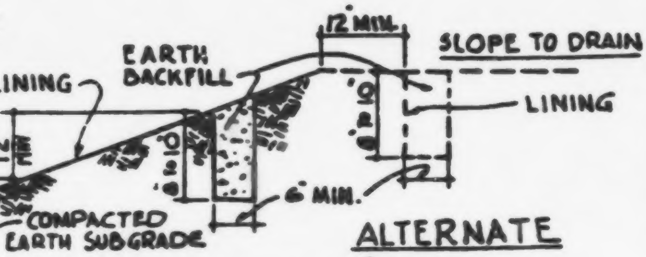
B. Preparation of Paved Surfaces. Concrete and other types of paved surfaces which are to be lined shall have all rough edges and projections removed in the area of lining. All cracks in the concrete shall be cleaned and filled with a sand-cement mortar. Extruded expansion joint material and joint sealers shall be cut off flush. The entire surface to be lined shall be cleaned of all foreign materials and swept thoroughly.


LINER-TO-CONC ADHESIVE
LINING
8" MIN
COMPACTED EARTH SUBGRADE
2"x1/8" AL METAL BATTEN STRIPS W/ RAMSET FASTENERS 12" O.C.
ALTERNATE BATTENS 1"x4" WOOD
LINER-TO-CONC ADHESIVE
LINER-CONCRETE WATERSTOP

CHOR TO CONCRETE STRUCTURES


EARTH BACKFILL
LINING
6"
WATER LEVEL
12" MIN
10"
6"
COMPACTED EARTH SUBGRADE

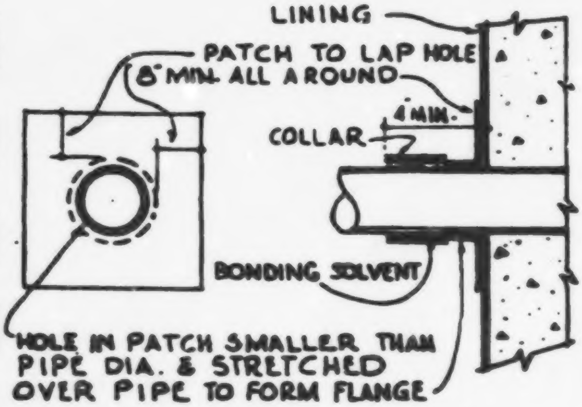
ANCHOR-METHOD #1


12" MIN
SLOPE TO DRAIN
EARTH BACKFILL
LINING
LINING
WATER LEVEL
12" MIN
6" MIN
COMPACTED EARTH SUBGRADE

ALTERNATE

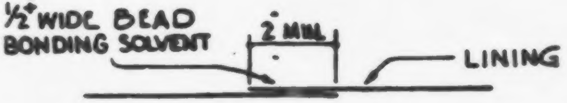
ANCHOR-METHOD #2

TOP OF SLOPE ANCHORAGE

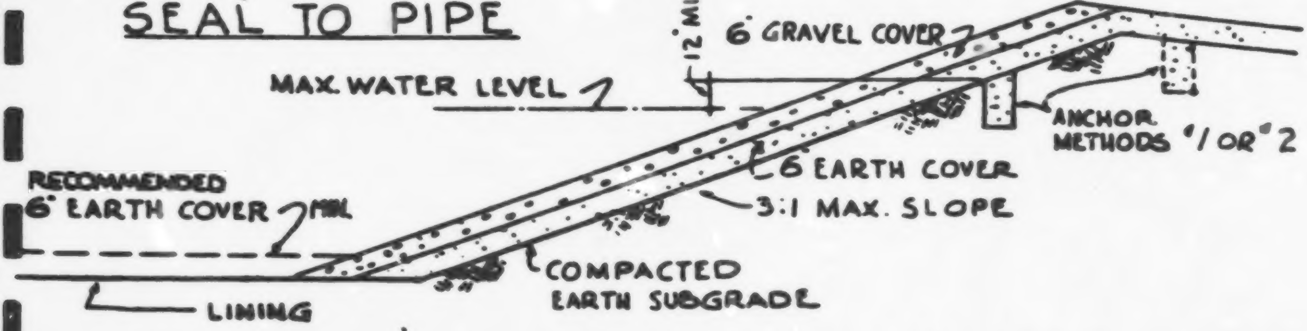

LINING
PATCH TO LAP HOLE 8" MIN ALL AROUND
4" MIN
COLLAR
BONDING SOLVENT
HOLE IN PATCH SMALLER THAN PIPE DIA. & STRETCHED OVER PIPE TO FORM FLANGE

ALTERNATE-OMIT PATCH & FORM FLANGE IN LINING

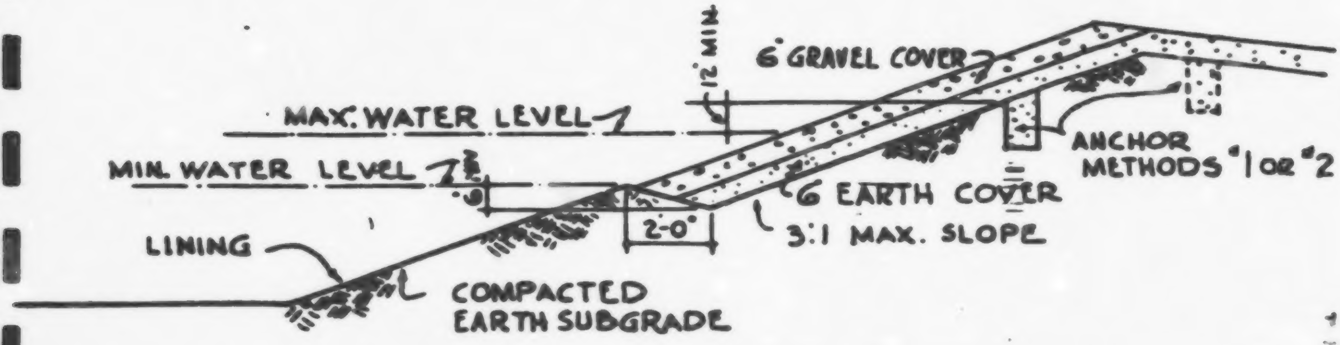
SEAL TO PIPE


1/2" WIDE BEAD BONDING SOLVENT
2" MIN
LINING

TYPICAL LAP JOINT


12" MIN.
6" GRAVEL COVER
MAX. WATER LEVEL
ANCHOR METHODS #1 OR #2
6" EARTH COVER
RECOMMENDED 6" EARTH COVER MIN.
3:1 MAX. SLOPE
COMPACTED EARTH SUBGRADE
LINING

EARTH & GRAVEL COVER – FULL SLOPES


12" MIN
6" GRAVEL COVER
MAX. WATER LEVEL
ANCHOR METHODS #1 OR #2
MIN. WATER LEVEL
6" EARTH COVER
2'-0"
3:1 MAX. SLOPE
LINING
COMPACTED EARTH SUBGRADE

EARTH & GRAVEL COVER - PARTIAL SLOPES

APPENDIX D-2-5

WATERSAVER COMPANY, INC.

WATERSAVER
W.
DENVER

FLEXIBLE MEMBRANE LINER INFORMATION MANUAL

WATERSAVER COMPANY, INC.

ENGINEERING SPECIFICATION GUIDE

.036 INDUSTRIAL GRADE HYPALON®

SUPPORTED WITH 10 × 10 1000d SCRIM

WATERSAVER CO., INC. ○ P.O. B[illegible] [illegible] ○ [illegible] Office [illegible]
Phone 303-623-[illegible] ○ [illegible] WATS [illegible] ○ [illegible] WATS 800-525-2424 ○

1. SCOPE

1.1 The scope covered by these specifications covers the furnishing and installation of a fabric-reinforced industrial grade Hypalon lining. All work shall be done in strict accordance with the engineers drawings and specifications.

2. CONTRACTOR'S EXPERIENCE

2.1 Any contractor proposing to perform the work hereunder shall have demonstrated his ability to do the work by having successfully installed at least two million square feet of reinforced membrane lining.

3. LINING MATERIAL

3.1 The membrane lining material shall be fabric-reinforced Hypalon of new, first-quality products designed and manufactured specifically for the purpose of this work, and shall have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer shall have produced, and have in service in similar applications for a period of not less than one (1) year, at least five (5) million square feet of fabric-reinforced industrial grade Hypalon material utilizing the same scrim specified for use under these specifications.

3.2 Hypalon utilized for encapsulation of the scrim shall be manufactured from a composition of high quality ingredients, suitably compounded, of which Hypalon 45 synthetic rubber resin is the sole elastomer. Zinc compounds of any kind, including zinc oxide, zinc stearate and zinc dusting agents, are prohibited. Dusting agents of any kind of prohibited on the finished product.

3.3 Scrim used in the membrane shall be 10 × 10 1000d polyester of an open type weave that permits strike-through of the Hypalon through the fabric to facilitate adhesion between the plies of Hypalon. The fill yarn must have 2.5 turns per inch maximum and 2.0 turns per inch minimum. All selvage edges must be trimmed prior to applying the Hypalon coating.

3.4 The composite membrane material shall consist of a thoroughly bonded, fabric-reinforced Hypalon rubber sheeting. It shall be manufactured by the calendering process and shall be uniform in color, thickness, size, and surface texture. The fabric shall be totally encapsulated between plies of Hypalon and shall not extend closer than 1/8 inch to the edge of the Hypalon coating either side of the fabric. Exposed fabric along longitudinal edges of roll stock and indications of delamination will not be permitted. The composite material shall be a flexible, durable, watertight product free of pinholes, blisters, holes, and contaminants and shall not delaminate in a water environment.

The composite membrane material shall be fabric-reinforced Hypalon consisting of one ply of scrim and two plies of Hypalon.

Property	Specification	Test Method
Tensile Strength, psi, min.	1500	ASTM D-412
Elongation, @ Break % min.	300	ASTM D-412
Water Absorption, (max. wt. gain), %		ASTM D-471
7 days @ 70°F	1.0	
14 days @ 70°F	1.0	
30 days @ 70°F	1.0	
14 days @ 158°F	30.0	
30 days @ 158°F	30.0	
Low Temperature, Cold Bend, 1/8" mandrel for 4 hrs., °F	-45	ASTM D-2136
Ozone Resistance (3 ppm @ 30% strain @ 104°F, 72 hrs.)	Pass	ASTM D-1149
Heat Aging, (14 days @ 212°F)		
Tensile Strength, psi, min.	1500	ASTM D-412
Elongation, % min.	150	

Property	Specification	Test Method
Thickness	.036 and not less than .033	ASTM D-751
Breaking Strength, lbs., min.	200	ASTM D-751 Grad Method
Tongue Tear, lbs., min.	80	ASTM D-413
Ply Adhesion, Machine Method 180° peel, lbs./2" width, min.	8	ASTM D-413 Method A

3.5 The fabricator shall be an experienced firm customarily engaged in factory-fabricating individual widths of fabric-reinforced Hypalon roll stock into large sheets. Factory seams shall have a minimum of 1-½" scrim to scrim overlap when made by the solvent seaming method, and 5/8 inch scrim to scrim overlap when made by the heat welded method.

Each factory-fabricated sheet shall be given prominent, unique indelible identifying markings indicating proper direction of unrolling and/or unfolding to facilitate layout and positioning in the field. Each factory-fabricated sheet shall be individually packaged in a heavy cardboard or wooden crate fully enclosed and protected to prevent damage to it during shipment, prominently identified in the same fashion as the sheet within and showing the date of shipment. Until installed, factory-fabricated sheets shall be stored in their original unopened crates; if outdoors, they shall be stored on pallet and shall be potected from the direct rays of the sun under a light-colored heat-reflective opague cover in a manner that provides a free-flowing air space between the crate and cover.

4. OTHER MATERIALS

4.1 Solvent for cleaning contact surfaces of field joints and for other required uses shall be as recommended by the manufacturer or approved fabricator of the fabric-reinforced Hypalon

4.2 All seaming, sealing and high-solids adhesives shall be of a type or types recommended by the manufacturer or approved fabricator of the fabric-reinforced Hypalon and shall be delivered in original sealed containers.

5. INSTALLATION

5.1 Prior to ordering fabric-reinforced Hypalon material, the contractor may submit, for the engineer's approval, shop drawings showing lining sheet layout with proposed size, number, position, of all factory-fabricated sheets and indicating the location of all field joints. Shop drawings may also show complete details and/or methods for anchoring the lining at top of slope, making field joints, seals at structures, etc.

5.2 Lap joints shall be used to seal factory-fabricated sheets of fabric-reinforced Hypalon together in the field. All field joints between sheets of fabric-reinforced Hypalon shall be made on a supporting smooth surface and, unless the weather is sufficiently warm, heat guns shall be used to make the sealing temperature at least 90°F. The lap joints shall be formed by lapping the edges of sheets a minimum of 3" scrim-to-scrim. The contact surfaces of the sheets shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials then wiped clean. Sufficient Hypalon-to-Hypalon bonding adhesive shall be applied to both contact surfaces in the joint area and the two surfaces pressed together while wet and immediately rolled. Any wrinkles shall be smoothed out and any cut edges of the fabric-reinforced Hypalon shall be sealed with a Hypalon adhesive to prevent wicking.

5.3 Any necessary repairs to the Hypalon membrane shall be patched with a piece of the membrane material itself and Hypalon-to-Hypalon adhesive. The adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, the two surfaces pressed together immediately and rolled, and any wrinkles smoothed out, all in accordance with Paragraph 5.2 hereof.

5.4 All joints, on completion of the work, shall be tightly bonded. Any membrane surface showing injury due to scuffing, penetration by foreign objects, or distress from other causes shall, as directed by the engineer, be replaced or repaired with an additional piece of fabric-reinforced Hypalon membrane of the proper size.

5.5 On completion of installation, the contractor shall dispose of all trash, waste, material and equipment used in connection with the work hereunder, and shall leave the premises in a neat and acceptable condition.

6. SEAM STRENGTH

6.1 All factory and field seams (joints) shall, after 12 days, have a seam strength of 200 pounds when tested in accordance with ASTM D-751, Grab Method (using 4" wide specimens having a length of 10" plus the seam width). The distance between the jaws of the testing apparatus at the start of the test must be 8" plus the seam width and shall have sufficient strength in peel that they fail by delamination from the scrim rather than in the plane of the seam.

ENGINEERING SPECIFICATION GUIDE

STEVENS INDUSTRIAL GRADE—HYPALON ® 45
.045" SUPPORTED WITH 10x10 1000D SCRIM

1. SCOPE

1.1 The scope covered by these specifications covers the furnishings and installation of a fabric-reinforced Hypalon lining. All work shall be done in strict accordance with the engineers drawings and specifications.

2. CONTRACTOR'S EXPERIENCE

2.1 Any contractor proposing to perform the work hereunder shall have demonstrated his ability to do the work by having successfully installed at least two million square feet of reinforced membrane lining.

3. LINING MATERIAL

3.1 The membrane used for lining material shall be fabric-reinforced Hypalon of new, first-quality products designed and manufactured specifically for the purpose of this work, and shall have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer shall have produced, and have in service in similar applications for a period of not less than one (1) year, at least ten (10) million square feet of fabric-reinforced Hypalon material utilizing the same scrim specified for use under these specifications.

3.2 Hypalon utilized for encapsulation of the scrim shall be manufactured from a composition of high quality ingredients, suitably compounded, of which Hypalon 45 synthetic rubber resin is the sole elastomer. Zinc compounds of any kind, including zinc oxide, zinc stearate and zinc dusting agents, are prohibited. Dusting agents of any kind are prohibited on the finished product.

Property	Test Method	Specification
Tensile Strength	ASTM D-412	1500 psi min.
Elongation @ Break	ASTM D-412	300% min.
Water Absorption	ASTM D-471 (7 days @ 70°F)	2% (wt) max.
Cold Bend (36 mil specimen, reinforced)	ASTM D-2136 (⅛" mandrel)	−45°F, no cracks
Brittleness Temp. (30 mil specimen, unreinforced)	ASTM D-746 Procedure B	−45°F, no failures
Ozone Resistance	ASTM D-1149 (3 ppm @ 30% strain @ 104°F — 72 hours)	No effect
Heat Aging	ASTM D-412 (14 days @ 212°F)	
Tensile Strength		1500 psi min.
Elongation @ Break		150% min.

All test values are based on .030" specimens.

3.3 Scrim used in the membrane shall be 10 × 10 1000D polyester of an open type weave that permits strike-through of the Hypalon through the fabric to facilitate adhesion between the plies of Hypalon. The fill yarn must have 2.5 turns per inch maximum and 2.0 turns per inch minimum. All selvage edges must be trimmed prior to applying the Hypalon coating.

3.4 The composite membrane material shall consist of a thoroughly bonded, fabric-reinforced Hypalon rubber sheeting. It shall be manufactured by the calendering process and shall be uniform in color, thickness, size, and surface texture. The fabric shall be totally encapsulated between plies of Hypalon and shall not extend closer than ⅛ inch to the edge of the Hypalon coating either side [illegible]e fabric. Exposed fabric along longitudinal edges of roll stock and indications of delamination will not be permitted. The composite material shall be a flexible, durable, watertight product free of pinholes, blisters, holes, and contaminants and shall not delaminate in a water environment.

The composite membrane material shall be fabric-reinforced Hypalon consisting of one ply of scrim and two plies of Hypalon as manufactured by Stevens Elastomeric And Plastic Products Inc., Easthampton, Massachusetts, or approved equal.

® DuPont trademark

WATERSAVER COMPANY, INC.

Property	Test Method	Specification
Thickness	ASTM D-751	.045 and not less than .041
Strength:		
Warp	ASTM D-751	200 Lbs.
Fill	Grab Method	200 Lbs.
Tear:		
Warp	ASTM D-751	80 Lbs.
Fill	Tongue Method 8 x 8 in. specimen	80 Lbs.
Ply Adhesion Lbs/in. width Minimum 180° peel back	ASTM D-413 Method A	10 Lbs.

3.5 The fabricator shall be an experienced firm customarily engaged in factory-fabricating individual widths of fabric-reinforced Hypalon roll stock into large sheets. Factory seams shall have a minimum of 1-½" scrim to scrim overlap when made by the solvent seaming method, and 1" scrim to scrim overlap when made by the heat welded method.

Each factory-fabricated sheet shall be given prominent, unique indelible identifying markings indicating proper direction of unrolling and/or unfolding to facilitate layout and positioning in the field. Each factory-fabricated sheet shall be individually packaged in a heavy cardboard or wooden crate fully enclosed and protected to prevent damage to it during shipment, prominently identified in the same fashion as the sheet within and showing the date of shipment. Until installed, factory-fabricated sheets shall be stored in their original unopened crates; if outdoors, they shall be stored on pallet and shall be protected from the direct rays of the sun under a light-colored heat-reflective opaque cover in a manner that provides a free-flowing air space between the crate and cover.

4. OTHER MATERIALS

4.1 Solvent for cleaning contact surfaces of field joints and for other required uses shall be as recommended by the manufacturer or approved fabricator of the fabric-reinforced Hypalon.

4.2 All seaming, sealing and high-solids adhesives shall be of a type or types recommended by the manufacturer or approved fabricator of the fabric-reinforced Hypalon and shall be delivered in original sealed containers.

5. INSTALLATION

5.1 Prior to ordering fabric-reinforced Hypalon material, the contractor shall submit, for the engineer's approval, shop drawings showing lining sheet layout with proposed size, number, position, of all factory-fabricated sheets and indicating the location of all field joints. Shop drawings shall also show complete details and/or methods for anchoring the lining at top of slope, making field joints, seals at structures, etc.

5.2 Lap joints shall be used to seal factory-fabricated sheets of fabric-reinforced Hypalon together in the field. All field joints between sheets of fabric-reinforced Hypalon shall be made on a supporting smooth surface and, unless the weather is sufficiently warm, heat guns shall be used to make the sealing temperature at least 90°F. The lap joints shall be formed by lapping the edges of sheets a minimum of 3" scrim-to-scrim. The contact surfaces of the sheets shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials, then wiped with 111 Trichloroethane. Sufficient Hypalon-to-Hypalon bonding adhesive shall be applied to both contact surfaces in the joint area and the two surfaces pressed together while wet and immediately rolled. Any wrinkles shall be smoothed out and any cut edges of the fabric-reinforced Hypalon shall be sealed with high solids Hypalon adhesive to prevent wicking.

5.3 Any necessary repairs to the Hypalon membrane shall be patched with a piece of the membrane material itself and Hypalon-to-Hypalon adhesive. The adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, the two surfaces pressed together immediately and rolled, and any wrinkles smoothed out, all in accordance with Paragraph 5.2 hereof.

5.4 All joints, on completion of the work, shall be tightly bonded. Any membrane surface showing injury due to scuffing, penetration by foreign objects, or distress from other causes shall, as directed by the engineer, be replaced or repaired with an additional piece of fabric-reinforced Hypalon membrane of the proper size.

5.5 On completion of installation, the contractor shall dispose of all trash, waste, material and equipment used in connection with the work hereunder, and shall leave the premises in a neat and acceptable condition.

6. SEAM STRENGTH

6.1 All factory and field seams (joints) shall, after 12 days, have a seam strength of 200 pounds when tested in accordance with ASTM D-751 Grab Method Modified (using 4" wide specimens having a length of 8" plus the seam width). The distance between the jaws of the test apparatus at the start of the test must be 6" plus the seam width, and shall have sufficient strength in a 180° peel back that the mode of failure shall be in the plane of the scrim rather than in the plane of the seam.

J. P. Stevens & Co., Inc.
ELASTOMERIC PRODUCTS DEPARTMENT
EASTHAMPTON, MA 01027 (413) 527-0700

LNJPSH 2/84

INDUSTRIAL GRADE HYPALON
J. P. STEVENS 60 MIL REINFORCED LINING

J. P. Stevens 60 mil membrane lining is a 3 ply construction of two plies Hypalon and encapsulated reinforcement of 10 X 10 1000 denier polyester scrim.

PHYSICAL SPECIFICATION

PROPERTY	TEST METHOD	SPECIFICATION
Gauge (nominal)	--	60
Thickness, mils minimum	ASTM D751	55
Breaking Strength-Fabric (pounds, minimum)	ASTM D751 Method A	300
Tear Strength (pounds, minimum)	ASTM D751	90
Low Temperature, °F	ASTM D2136 1/8 in. mandrel 4 hrs., Pass	-40
Dimensional Stability (each direction percent change maximum)	ASTM D1204 212°F, 1 hr.	4
Volatile Loss (percent loss maximum	ASTM D1203 Method A 30 mil sheet	0.5
Hydrostatic Resistance (lbs./sq. in. minimum)	ASTM D751 Method A Procedure 1	300
Ply Adhesion (each direction, lbs./in. width minimum)	ASTM D413 Machine Method Type A	8
Water Absorption (percent weight gain maximum-30 mil unsupported sheet)	ASTM D471	
	14 days @ 70°F	1.5
	30 days @ 70°F	2.0
	14 days @ 158°F	30.0
	30 days @ 158°F	30.0

CHEMICAL REAGENT DATA SHEET
INDUSTRIAL GRADE HYPALON®

WATERSAVER CO., INC. ⊃ P.O. Box [illegible] Denver [illegible] ⊃ [illegible]
Phone: [illegible] ⊃ [illegible] ⊃ [illegible]

REAGENTS	% SOLUTION	pH	PERCENT WEIGHT GAINS 70 HRS.	11 DAYS	91 DAYS
Acetic Acid	5	2.9	1.2	2.2	6.6
Acetone	100	2.4	7.2	7.0	7.7
Ammonium Hydroxide	10	12.1	2.0	4.5	14.0
Aniline	100	9.1	23.2	21.0	21.6
Benezene	100	10.9	dissolved	0	0
Carbon Tetrachloride	100	1.0	dissolved	0	0
Citric Acid	1	1.9	1.0	0.9	0.3
Cottonseed Oil	100	N/A	2.0	3.6	7.3
Detergent, Heavy Duty	0.025	10.5	0.7	1.0	1.0
Dimethylformamide	100	13.1	10.8	11.0	10.7
Ethyl Alcohol	50	4.8	0.8	0.9	0.1
Ethyl Acetate	100	8.1	16.0	16.5	13.7
Ethyl Dichloride	100	7.7	152.8	148.6	237.6
Hexane	100	6.8	7.4	7.8	10.4
Hydrochloric Acid	10	1.3	0.2	0.9	0.08
Hydrogen Peroxide, 28%	3	3.5	0.2	0.9	0.3
Isooctane	100	10.4	5.0	5.2	7.0
Kerosene	100	4.0	30.7	26.7	42.5
Mineral Oil	100	N/A	1.0	1.4	2.8
Methyl Alcohol	100	6.4	0.6	0.6	0.2
Nitric Acid	40	0	1.3	2.7	13.0
Nitric Acid	10	.5	0.4	0.5	3.0
Oleic Acid	100	1.8	5.5	7.8	8.6
Olive Oil	100	N/A	1.4	2.0	5.0
Phenol	5	6.0	5.6	6.0	6.0
Sodium Carbonate	20	11.2	1.0	0.8	0.9
Sodium Carbonate	2	11.6	0.9	0.8	0.3
Sodium Chloride	10	9.2	1.3	1.2	1.0
Sodium Hypochlorite	100	12.2	1.0	0.6	0.4
Sodium Hydroxide	60	8.3	0.3	1.0	0.5
Sodium Hydroxide	10	12.3	0.4	0.7	0.5
Sodi[illegible]droxide	1	12.5	0.3	0.7	0.2
S[illegible]on	1	10.1	0.5	0.3	−0.7
[illegible]	30	.7	0.2	0.7	0.3
[illegible]	3	1.5	0.2	0.7	−0.5
[illegible]	100	.7	dissolved	0	0
Transformer Oil #55	100	N/A	17.2	25.7	45.0
Turpentine	100	4.6	125.8	123.0	dissolved
Water — Distilled	100	5.0	0.7	0.8	0.7
Water — Tap	100	7.6	0.8	0.9	1.2

Above tests are run under ASTM D 471, Immersion Method.
Weight gains are expressed in percent.
Tests were run at room temperature 75°F.

J. P. Stevens & Co., Inc.
ELASTOMERIC PRODUCTS DEPARTMENT
EASTHAMPTON, MA 01027 (413) 527-0700

June 22, 1983

Mr. Jim Bryan
Watersaver Co., Inc.
P. O. Box 16465
Denver, Colorado 80216

RE:

Uranium Project

Test results of sample membrane taken from the Uranium Project.

Specimens received were labeled: North Top
North Bottom
East Top
East Bottom

Specimens as received were in excellent condition. The Hypalon rubber was firm and smooth with no indication of deterioration.

TEST METHODS

Breaking Strength	ASTM D751 Grab Method
Tear Strength	ASTM D751 Tongue Tear Method
Puncture Resistance	FTM 101B Method 2031

Factory seam test per ASTM D816 1" X 4" plus seam width.
Factory and field seam strength per modified ASTM 751 - specimen size 4" wide X 9" long plus seam width.

TEST RESULTS

Breaking Strength - ASTM D751 Lbs. Grab Method

North Top	275	285	285	271
North Bottom	297	315	297	312
East Top	287	298	289	297
East Bottom	306	327	323	325

Tear Strength - ASTM D751 Lbs. Tongue Tear Method

North Top	41	40	40	50
North Bottom	43	4[illegible]	42	46
East Top	40	45	48	50
East Bottom	31	35	28	26

Puncture Resistance - FTMS 101^{B} Method 2031

North Top	173	180	190	170
North Bottom	175	185	180	194
East Top	173	173	175	185
East Bottom	180	183	174	170

NOTE: Table II of the original specification called for a "factory and field seam strength each direction (minimum % of tensile strength of parent material)

Required value: 100%

Test Method: ASTM D816 (Method "B")

ASTM D816 Title is: Standard Methods of Testing Rubber Cements

Because the test specimens are 1" X 5" each with 1 square inch of bonded area at the overlap, it is impossible to measure the true tensile strength or breaking strength of the parent material compared to the ASTM D751 Grab Method specimens which are 4" X 6" and are tested with a 1 inch wide jaw.

In order to develop a comparison per ASTM D816 we cut specimens from the parent material 1 inch wide and compared the results of 1 inch wide Factory seamed (dielectric) material. This is confirmed in my letter (attached) to Watersaver, dated February 22, 1980.

Original	Parent Material:	131.2 lbs. avg.
Original	Factory Seam:	143.2 lbs. avg.

Aged test results per ASTM D816

Factory Seam failure was outside the seam area.

North Top	88	94	113	94	99

It has been generally accepted that a more realistic test method for testing of seams is to use a modified ASTM D751 with the seam specimen 4 inches wide X 9 inches long plus seam width compares to ASTM D751 Grab Method 4 inch X 6 inch specimen. This is covered in detail in a second letter dated February 22, 1980 (attached). This method is also referenced by USEPA Office of Solid Waste and Emergency Response SW 870 March 1983 revised edition of Lining of Waste Impoundment and Disposal Facilities page 413. This page is attached to this report.

TEST RESULTS per ASTM D751 - modified specimen 4" X 9" plus seam width

Parent Material: 4" X 6" specimen	260	255	250	250	260
Original Seam: 4" X 9" specimen	290	285	270	285	275
North Top: (Factory Seam)	347	313	348	327	

Failure was at the jaw with no distortion of the seam. Elongation at break was 72% to 80%, and fabric break occurred simultaneously at the values indicated.

Normally, elongation measurements along the tensile properties of a finished reinforced lining are of minor concern as all membranes have adequate elongations of 20% to 700%. When the liner samples were received, our people went about testing the specimens as we normally would without regard to elongation. Thus, the figures for Breaking Strength Grab Method per ASTM D751 are cited at the point in which the fabric broke. This is cited in the specification as being the correct way to test.

A review of the original specification provides for fabric test per ASTM D751 Grab Method of 60 lbs. and 15% elongation and the rubber 100 lbs. and 150% elongation. A typical test report of the fabric when it is received from the Dunean Plant at Greenville, S.C., is attached.

The rubber itself is part of the rubber, scrim matrex, and it is difficult to separate to two in order to obtain a good idea of the rubber elongation after aging. However, we did take four more specimens from the north top and remeasured the fabric break and elongation at fabric break:

ASTM D751 GRAB METHOD 4" X 6" Specimens
NORTH TOP

	FABRIC BREAK	ELONGATION @ FABRIC BREAK
Fill Direction	306	25%
	313	25%
Warp Direction	293	20%
	300	20%

The elongation at fabric break compares to the original elongation of the scrim fabric while the fabric break is much higher. This higher figure is due to the influence of the rubber coating which has developed higher cured tensile strength and has developed a higher degree of shear strength bond of rubber to scrim resulting in a wider load distribution.

The curing effect of Hypalon rubber can be seen by the attached Maui, Hawaii study for non-reinforced Hypalon over a 5 year period. Both the tensile strength and 100% modulus increased while the elongations decreased. This, and other studies, indicate that after 15 years the black Hypalon will cure to an elongation range of 100% to 140% at break.

SUMMARY:

The test results indicate a normal cure of the Hypalon is taking place. After curing the values which we could measure still exceed the original specification.

	ORIGINAL REQUIREMENT	AGED RESULT
Puncture Resistance Lbs. Min.	120	170 - 194
Breaking Strength		
Fabric Lbs. Min.	60	271 - 312
Elongation % Min.	15	20 - 25
Tear Strength Lbs. Min.	15	26 - 50
Cold Bend per ASTM D2136	-45°F	Pass -45°F (5 of 5)

We hope this information is of help to you and thank you for sending the material for testing, as it helps us in establishing aged field data.

Sincerely,

J. P. STEVENS & CO., INC.
Elastomeric Products Department

Arnold G. Peterson
Technical Director

AGP/sdl

Enclosures

Stevens Elastomeric And Plastic Products Inc.

A SUBSIDIARY OF J. P. STEVENS & CO., INC.
EASTHAMPTON, MASS 01027 (413) 527-0700

April 30, 1979

Mr. Jim Bryan
Watersaver Company
P. O. Box 16465
Denver, Colorado 80216

Dear Jim;

The attached graphs show the difference between a standard potable water grade Hypalon and our Industrial Grade Hypalon.

The tests were standard weight gain tests per ASTM D471 at the time and temperature noted on the graphs.

The weight gain for the uranium mill tailing solution is very revealing as it supports the contention that the Industrial Grade Hypalon comes to equilibrium very quickly with a very low weight gain after 300 days at 70°C (158°F). As you know, there is concern about the effect of these uranium mill tailings on a Hypalon lining membrane, as no one has much data to show regarding long term effect. The data here is perhaps the best effort to date.

The data graphs will fit the data books your sales personnel have.

We appreciate your continued support to make Stevens Hypalon membrane the best product available.

Sincerely,

STEVENS ELASTOMERIC & PLASTIC PRODUCTS INC.
A Subsidiary of J. P. Stevens & Co., Inc.

Arnold G. Peterson

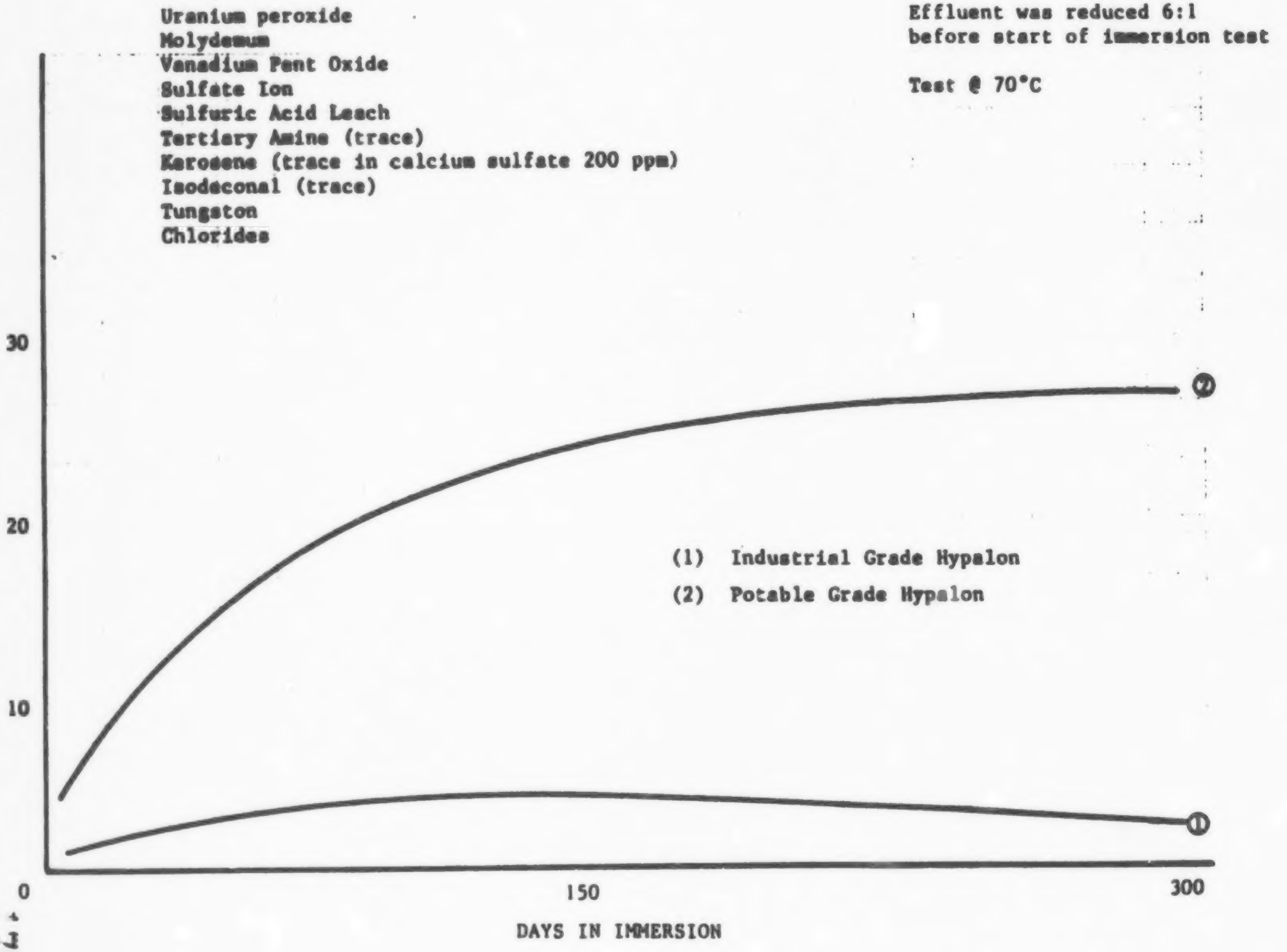
Arnold G. Peterson
Technical Director
Calendered Products

AGP/sl
cc: B. Slifer
R. Thorpe, H. Landry, L. Coco

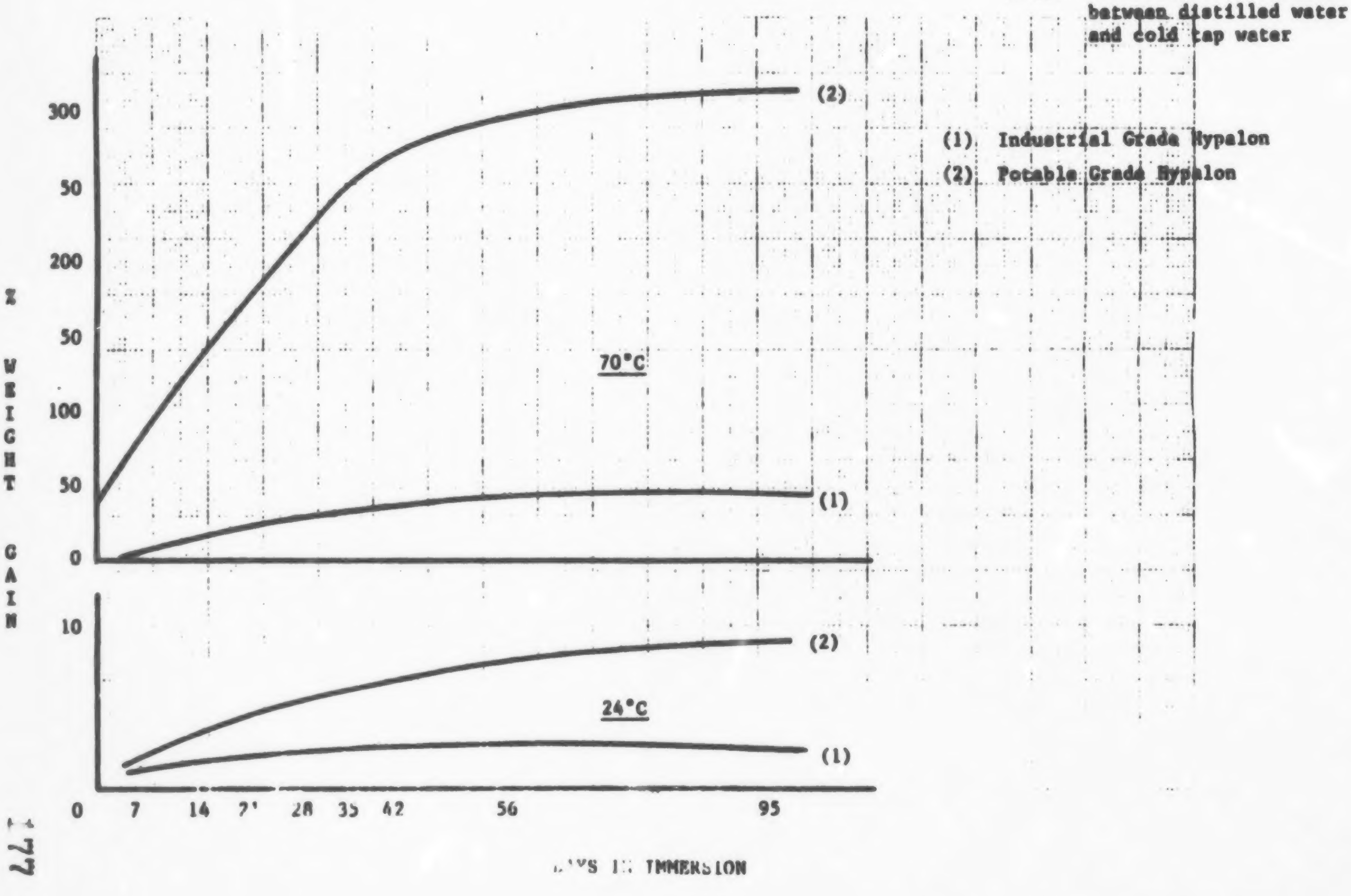
Enclosures

All statements herein are expressions of opinion, which by performance and testing are believed to be accurate and reliable; but are presented without guarantee or responsibility on our part. Statements concerning possible use of our products are made without any knowledge that such recommended uses may infringe any patent. No warranty of any kind whatsoever, expressed or implied, is made or intended.

TEST #125 Liquon from Uranium Mill Tailings



TEST #144 Water Immersion


NOTE: No dramatic differance between distilled water and cold tap water

Dynamit Nobel

DYNAMIT NOBEL OF AMERICA INC 10 LINK DRIVE, ROCKLEIGH, NEW JERSEY 07647 PHONE (201) 767-1660 TELEX 135-240

ALL WELL WRITTEN SPECIFICATIONS FOR PVC AND CPE MEMBRANE LINER MATERIALS MUST CONTAIN THE FOLLOWING IN WORD FORM IN ADDITION TO THE PHYSICAL PROPERTY REQUIREMENTS IN ORDER TO INSURE FIRST QUALITY PRODUCTS ARE SPECIFIED.

RECOMMENDED PVC SPECIFICATION STATEMENTS

MUST pass all physical property requirements

* **BIOCIDES**: Must contain biocide at a viable formulation level

NO deep gas checks or surface divits

GOOD surface quality

NO cold flow

NO unmixed formulation ingredients or compound

NO windows

* **MUST** not require an adhesive for seaming that is chemically different from the liner material itself

* **MUST** be formulated from 100% virgin domestic, first quality raw materials

* **MUST** not contain any setup or trim materials that are foreign to the virgin formulation

* **ONLY** first quality **Phthalate** and/or **Phosphate** plasticizers shall be used

* **THE** use of water soluable formulation ingredients is prohibited

RECOMMENDED CPE SPECIFICATION STATEMENTS

MUST pass all physical property requirements

* **MUST** contain a minimum of 45% Dow CPE Resin based on total weight of compound (this is equivalent to greater than 60% CPE Resin based on total weight of the polymer content)

* **MUST** not contain any plasticizers

* **MUST** be formulated from 100% virgin domestic, first quality raw materials

* **MUST** not require an adhesive for seaming that is chemically different from the liner itself

NO deep gas checks or surface divits

GOOD surface quality

NO cold flow

NO unmixed formulation ingredients or compound

NO windows

* **MUST** not contain any setup or trim materials that are foreign to the virgin formulation

* **THE** use of water soluable formulation ingredients is prohibited

But since, generally, chemical resistance is the most important factor, one must be aware of the difference thickness makes with regard to chemical resistance.

PVC Manufacturers currently manufacturing a viable pond liner grade PVC sheeting only offer warrantees on material 20 mils in thickness or greater. In a suitable application, 20 mil PVC can be warranteed for a period of up to 20 years. Although a 30 mil PVC in the same application would be expected to last a significantly longer period of time, the state-of-the-art and the limited experience period (about 15-20 years) prevents PVC manufacturers from going beyond the 20-year warrantee period for the 30-gauge product at this time.

R. H. Dickinson, Technical Marketing Manager

Dynamit Nobel of America Inc.

Dynamit Nobel

DYNAMIT NOBEL OF AMERICA INC. 10 LINK DRIVE, ROCKLEIGH, NEW JERSEY 07647 PHONE (201) 767-1660 TELEX 135-240

PVC FML SHEETING

Useful Service Life Expectandy

versus

Thickness

Generally one expects that the increase in the mass (thickness of a material) is the only reason that an increase in service-life can be expected since in the case where the same type of material is being considered it would be reasonable to expect equal chemical resistance regardless of thickness. This type of logic is probably most often applied to flexible PVC liners because it is well known that plasticizers are lost, with time, from PVC until the material finally becomes non-functional. Knowing this, one would naturally think that the thicker the PVC, the more plasticizer that is available for loss and therefore it will take longer.

The above, although partially true due to the ratio of surface area to mass, is not the primary consideration.

When chemical, or extraction, resistance is a consideration, any strain (as the result of a stress) increases the propensity of all flexible membrane liners to degrade. PVC is no exception.

To support this argument one only has to refer to the "actual" modulus (@100% elongation) values shown for 10, 20, and 30 mil PVC (or any other unsupported material). Using PVC as a reference, one will note that the "actual" modulus (stress) values at 100% elongation (extension) of 10, 20, and 30 mil PVC are 9, 20 and 30 pounds respectively. Any one of these materials at 100% extension would be much more susceptible to chemical attack or extraction than in their relaxed state.

It must be realized, however, that under a nine-pound stress the 20 and 30 mil materials would not be elongated 100%. The 20 mil perhaps 50% and the 30 mil almost not at all. These facts relate directly to field performance where stress points due to rocks or other raised objects in the subgrade are present under the liner. In summary, the more the strain, the less the chemical resistnace and the greater the thickness (and thereby, strength) the less the possibility that a strain will be present in an installation.

So as not to overlook the other added strength benefits that are inherent with greater thicknesses, one must also be aware ot the increased tensile, elongation, tear, etc. properties.

ENGINEERING SPECIFICATION GUIDE
.010 POLYVINYL CHLORIDE (PVC) MEMBRANE LINER

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a polyvinyl chloride (PVC) plastic lining in the (lagoon, reservoir, canal, etc.) where shown on the drawings or directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and subject to the terms and conditions of the contract.

02 - PVC MATERIALS

A. **General.** The materials supplied under these specifications shall be first quality products and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq. ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures.

B. **Description of PVC Matericals.** PVC (polyvinyl chloride) plastic lining shall consist of 76" (193 cm) widths of calendered polyvinyl chloride sheeting fabricated into large sections by means of special factory-bonded seams into a single panel, or into the minimum number of large panels required to fit the jobsite as supplied by WATER-SAVER CO., INC., P.O. Box 16465, Denver, Colorado (303-623-4111).

1. **Physical Characteristics** - The PVC materials shall have the following physical characteristics.

PROPERTIES	VALUE	TEST METHOD
Color	Black	
Thickness, mils., ± 7%	10	ASTM D-1593
Tensile Strength, min., psi	2400	ASTM D-882
(lbs./in. width, min.)	(24)	
Modulus @ 100% Elongation min. psi	900	ASTM D-882
(lbs./in. width, min.)	(9)	ASTM D-882
Ultimate Elongation, % min.	250	ASTM D-882
Tear Resistance:		
(a) Elmendorf, grams, min.	1600	ASTM D-1922
(gms./mil., min.)	(160)	
(b) Graves Tear, lbs. min.	3.25	ASTM D-1004
(lbs./in. min.)	(325)	
Low Temperature Impact, Pass, °F	-10	ASTM D-1790
Volatility, % loss, max.	1.50	ASTM D-1203
Water Extraction		
(@ 104°F, 24 hrs.) % loss, max.	0.45	ASTM D-1239
Specific Gravity, min.	1.23	ASTM D-792
Dimensional Stability		
(@ 212°F, 15 min.) % max. change	5.0	ASTM D-1204
Resistance to Soil Burial:		
Tensile Strength Loss, % max.	5.0	ASTM D-3083
Elongation Loss, % max.	20.0	

2. PVC materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for the use in hydraulic facilities. Reprocessed material shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of at least 76" (193 cm). Thickness shall be as shown on the drawings. Certification test results showing that the sheeting meets the specifications shall be supplied on request.

03 - FACTORY FABRICATION

Individual calender widths of PVC shall be factory fabricated into large panels.

The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures. Lap joints with a minimum joint width of ½ inch (13 mm) shall be used. Factory made splices shall have a strength of 80% of the specified sheet strength. After fabrication, the lining shall be accordion folded in both directions and packaged for minimum handling in the field. Shipping boxes shall be substantial enough to prevent damage to contents.

04 - PLACING OF PVC LINING

A. **General** - Installation shall be performed by a contractor that has previously installed a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of this material or by a contractor that has a fabricator field representative in attendance. The surface (substrate) to receive the liner shall be smooth, and free of sharp objects that could puncture the lining. All vegetation must be removed. A soil sterilant may be required at the discretion of the Engineer. The PVC lining shall be placed over the prepared surfaces to be line in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on the drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets and other projections through the lining. Any portion of lining damaged during installation shall be removed or repaired by using an additional piece of lining as specified hereinafter.

1. **Field Joints** - Lap joints will be used to seal factory fabricated panels of PVC together in the field. Lap joints shall be formed by lapping the edges of panels a minimum of 2 inches (50 mm). The contact surfaces of the panels shall be wiped clean to remove all dirt, dust or other foreign materials. Sufficient cold-applied vinyl to vinyl bonding adhesive shall be applied to the contact surfaces in the joint area, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out. Field made splices shall have a strength of 80% of the specified sheet strength.

2. **Joints to Structures** - All curing compounds and coatings shall be completely removed from the joint area. Joining of PVC to concrete shall be made with vinyl to concrete adhesive and mechanically fastened. Unless otherwise shown on the drawings, the minimum width of concrete to PVC joint shall be 8 inches (20 cm).

3. **Repairs to PVC** - Any necessary repairs to the PVC shall be patched with the lining material itself and cold applied vinyl to vinyl splicing adhesive. The splicing adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. **Quality of Workmanship** - All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC of the proper size. A Technical Service Representative will be made available to the contractor if the contractor desires. The contractor will bear the expense of this Technical Service Representative. The Technical Service Representative is not directly responsible for the quality of the work involved; such responsibility will be solely that of the contractor.

ENGINEERING SPECIFICATION GUIDE
.020 POLYVINYL CHLORIDE (PVC) MEMBRANE LINER

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a polyvinyl chloride (PVC) plastic lining in the (lagoon, reservoir, canal, etc.) where shown on the drawings or directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and subject to the terms and conditions of the contract.

02 - PVC MATERIALS

A. **General.** The materials supplied under these specifications shall be first quality products and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq. ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures.

B. **Description of PVC Matericals.** PVC (polyvinyl chloride) plastic lining shall consist of 76" (193 cm) widths of calendered polyvinyl chloride sheeting fabricated into large sections by means of special factory-bonded seams into a single panel, or into the minimum number of large panels required to fit the jobsite as supplied by WATER-SAVER CO., INC., P.O. Box 16465, Denver, Colorado (303-623-4111).

1. **Physical Characteristics** - The PVC materials shall have the following physical characteristics.

PROPERTIES	VALUE	TEST METHOD
Color	Black	--
Thickness, mils., ± 5%	20	ASTM D-1593
Tensile Strength, min., psi	2400	ASTM D-882
(lbs./in. width, min.)	(48)	
Modulus @ 100% Elongation min. psi	1000	ASTM D-882
(lbs./in. width, min.)	(20)	ASTM D-882
Ultimate Elongation, % min.	300	ASTM D-882
Tear Resistance:		
(a) Elmendorf, grams, min.	4000	ASTM D-1922
(gms./mil., min.)	(200)	
(b) Graves Tear, lbs. min.	5.5	ASTM D-1004
(lbs./in. min.)	(275)	
Low Temperature Impact, Pass, °F	-20	ASTM D-1790
Volatility, % loss, max.	1.0	ASTM D-1203
Water Extraction		
(@ 104°F, 24 hrs.) % loss, max.	0.3	ASTM D-1239
Specific Gravity, min.	1.23	ASTM D-792
Dimensional Stability		
(@ 212°F, 15 min.) % max. change	5.0	ASTM D-1204
Resistance to Soil Burial:		
Tensile Strength Loss, % max.	5.0	ASTM D-3083
Elongation Loss, % max.	20.0	

2. PVC materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for the use in hydraulic facilities. Reprocessed material shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of at least 76" (193 cm). Thickness shall be as shown on the drawings. Certification test results showing that the sheeting meets the specifications shall be supplied on request.

03 - FACTORY FABRICATION

Individual calender widths of PVC shall be factory fabricated into large panels.

The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures. Lap joints with a minimum joint width of ½ inch (13 mm) shall be used. Factory made splices shall have a strength of 80% of the specified sheet strength. After fabrication, the lining shall be accordion folded in both directions and packaged for minimum handling in the field. Shipping boxes shall be substantial enough to prevent damage to contents.

04 - PLACING OF PVC LINING

A. **General** - Installation shall be performed by a contractor that has previously installed a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of this material or by a contractor that has a fabricator field representative in attendance. The surface (substrate) to receive the liner shall be smooth, and free of sharp objects that could puncture the lining. All vegetation must be removed. A soil sterilant may be required at the discretion of the Engineer. The PVC lining shall be placed over the prepared surfaces to be line in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on the drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets and other projections through the lining. Any portion of lining damaged during installation shall be removed or repaired by using an additional piece of lining as specified hereinafter.

1. **Field Joints** - Lap joints will be used to seal factory fabricated panels of PVC together in the field. Lap joints shall be formed by lapping the edges of panels a minimum of 2 inches (50 mm). The contact surfaces of the panels shall be wiped clean to remove all dirt, dust or other foreign materials. Sufficient cold-applied vinyl to vinyl bonding adhesive shall be applied to the contact surfaces in the joint area, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out. Field made splices shall have a strength of 80% of the specified sheet strength.

2. **Joints to Structures** - All curing compounds and coatings shall be completely removed from the joint area. Joining of PVC to concrete shall be made with vinyl to concrete adhesive and mechanically fastened. Unless otherwise shown on the drawings, the minimum width of concrete to PVC joint shall be 8 inches (20 cm).

3. **Repairs to PVC** - Any necessary repairs to the PVC shall be patched with the lining material itself and cold applied vinyl to vinyl splicing adhesive. The splicing adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. **Quality of Workmanship** - All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC of the proper size. A Technical Service Representative will be made available to the contractor if the contractor desires. The contractor will bear the expense of this Technical Service Representative. The Technical Service Representative is not directly responsible for the quality of the work involved; such responsibility will be solely that of the contractor.

ENGINEERING SPECIFICATION GUIDE
.030 POLYVINYL CHLORIDE (PVC) MEMBRANE LINER

01 - GENERAL REQUIREMENTS

The work covered by these specifications consists of installing a polyvinyl chloride (PVC) plastic lining in the (lagoon, reservoir, canal, etc.) where shown on the drawings or directed by the Engineer. All work shall be done in strict accordance with the drawings and these specifications and subject to the terms and conditions of the contract.

02 - PVC MATERIALS

A. **General.** The materials supplied under these specifications shall be first quality products and manufactured specifically for the purposes of this work, and which have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq. ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures.

B. **Description of PVC Matericals.** PVC (polyvinyl chloride) plastic lining shall consist of 76" (193 cm) widths of calendered polyvinyl chloride sheeting fabricated into large sections by means of special factory-bonded seams into a single panel, or into the minimum number of large panels required to fit the jobsite as supplied by WATER-SAVER CO., INC., P.O. Box 16465, Denver, Colorado (303-623-4111).

1. **Physical Characteristics** - The PVC materials shall have the following physical characteristics.

PROPERTIES	VALUE	TEST METHOD
Color	Black	
Thickness, mils., ± 5%	30	ASTM D-1593
Tensile Strength, min., psi	2200	ASTM D-882
(lbs./in. width, min.)	(66)	
Modulus @ 100% Elongation min. psi	1000	ASTM D-882
(lbs./in. width, min.)	(30)	ASTM D-882
Ultimate Elongation, % min.	325	ASTM D-882
Tear Resistance:		
(a) Elmendorf, grams, min.	6000	ASTM D-1922
(gms./mil., min.)	(200)	
(b) Graves Tear, lbs. min.	8.25	ASTM D-1004
(lbs./in. min.)	(275)	
Low Temperature Impact, Pass, °F	-20	ASTM D-1790
Volatility, % loss, max.	0.75	ASTM D-1203
Water Extraction		
(@ 104°F, 24 hrs.) % loss, max.	0.25	ASTM D-1239
Specific Gravity, min.	1.23	ASTM D-792
Dimensional Stability		
(@ 212°F, 15 min.) % max. change	5.0	ASTM D-1204
Resistance to Soil Burial:		
Tensile Strength Loss, % max.	5.0	ASTM D-3083
Elongation Loss, % max.	20.0	

2. PVC materials shall be manufactured from domestic virgin polyvinyl chloride resin and specifically compounded for the use in hydraulic facilities. Reprocessed material shall not be used. It shall be neutral gray to black in color and produced in a standard minimum width of at least 76" (193 cm). Thickness shall be as shown on the drawings. Certification test results showing that the sheeting meets the specifications shall be supplied on request.

03 - FACTORY FABRICATION

Individual calender widths of PVC shall be factory fabricated into large panels.

The manufacturer of the calendered rolls shall show where a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of its 76" (193 cm) wide material has been installed for lining hydraulic structures. Lap joints with a minimum joint width of ½ inch (13 mm) shall be used. Factory made splices shall have a strength of 80% of the specified sheet strength. After fabrication, the lining shall be accordion folded in both directions and packaged for minimum handling in the field. Shipping boxes shall be substantial enough to prevent damage to contents.

04 - PLACING OF PVC LINING

A. **General** - Installation shall be performed by a contractor that has previously installed a minimum of 2,000,000 sq.ft. (185,000 sq.m.) of this material or by a contractor that has a fabricator field representative in attendance. The surface (substrate) to receive the liner shall be smooth, and free of sharp objects that could puncture the lining. All vegetation must be removed. A soil sterilant may be required at the discretion of the Engineer. The PVC lining shall be placed over the prepared surfaces to be line in such a manner as to assure minimum handling. It shall be sealed to all concrete structures and other openings through the lining in accordance with details shown on the drawings submitted by the contractor and approved by the Engineer. The lining shall be closely fitted and sealed around inlets, outlets and other projections through the lining. Any portion of lining damaged during installation shall be removed or repaired by using an additional piece of lining as specified hereinafter.

1. **Field Joints** - Lap joints will be used to seal factory fabricated panels of PVC together in the field. Lap joints shall be formed by lapping the edges of panels a minimum of 2 inches (50 mm). The contact surfaces of the panels shall be wiped clean to remove all dirt, dust or other foreign materials. Sufficient cold-applied vinyl to vinyl bonding adhesive shall be applied to the contact surfaces in the joint area, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out. Field made splices shall have a strength of 80% of the specified sheet strength.

2. **Joints to Structures** - All curing compounds and coatings shall be completely removed from the joint area. Joining of PVC to concrete shall be made with vinyl to concrete adhesive and mechanically fastened. Unless otherwise shown on the drawings, the minimum width of concrete to PVC joint shall be 8 inches (20 cm).

3. **Repairs to PVC** - Any necessary repairs to the PVC shall be patched with the lining material itself and cold applied vinyl to vinyl splicing adhesive. The splicing adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, and the two surfaces pressed together immediately. Any wrinkles shall be smoothed out.

4. **Quality of Workmanship** - All joints, on completion of the work, shall be tightly bonded. Any lining surface showing injury due to scuffing, penetration by foreign objects or distress from rough subgrade shall, as directed by the Engineer, be replaced or covered and sealed with an additional layer of PVC of the proper size. A Technical Service Representative will be made available to the contractor if the contractor desires. The contractor will bear the expense of this Technical Service Representative. The Technical Service Representative is not directly responsible for the quality of the work involved; such responsibility will be solely that of the contractor.

WATERSAVER
DENVER

CHEMICAL REAGENT DATA SHEET
(PVC) POLYVINYL CHLORIDE

REAGANTS	% SOLUTION	PERCENT WEIGHT LOSSES 1 DAY	7 DAYS	28 DAYS
Acetic Acid	2	0.2	0.1	0.1
Acetic Acid	10	0.1	0.1	0.1
Benzene	100	deteriorated		
Diesel Fuel	100	6.5	11.6	12.6
Ethylene Glycol	100	0.4	1.1	1.2
Gasoline	100	23.0	24.0	24.0
Hydrochloric Acid	concentrated	+ 1.9	+ 0.5	+ 2.0
Hydrochloric Acid	10	0.1	0.1	0.2
JP-4 Jet Fuel	100	20.8	20.0	20.2
Kerosene	100	17.8	17.7	18.8
Methanol	5	0.1	0.1	0.2
Methanol	50	0.1	+ 0.2	+ 0.5
Methanol	100	13.4	20.6	24.0
SAE 30 Motor Oil	100	2.1	5.1	8.7
Nitric Acid	concentrated	3.4	13.1	16.1
Nitric Acid	10	+ 0.2	+ 0.6	+ 1.9
Phenol	5	6.2	14.7	16.4
Phenol	100	deteriorated		
Sodium Chloride (Aqueous)	concentrated	0.1	0.1	0.1
Sodium Hydroxide	2	0.2	0.4	0.5
Sodium Hydroxide	10	0.3	0.8	3.0
Sulfuric Acid	concentrated	deteriorated		
Sulfuric Acid	10	0.4	0.2	0.1
Tetrachloro Ethylene	100	deteriorated		
Toluene	100	deteriorated		
Water - Tap	100	0.1	0.2	0.2

The above tests were run under ASTM D 471, Immersion Method.
Weight losses are expressed in percent.
Tests were run at room temperature 75°F.
Above results were based on .030 thickness.

PVC - CRDS: 0282

CHEMICAL REAGENT DATA SHEET
(PVC) POLYVINYL CHLORIDE

ENGINEERING SPECIFICATION GUIDE
.036 OIL RESISTANT CPER
SUPPORTED WITH 10 x 10 1000d SCRIM

WATERSAVER CO., INC. [illegible] 58th Ave.
[illegible] WATS 800 525 2424 [illegible]

1. SCOPE

1.1 The scope covered by these specifications covers the furnishing and installation of a fabric-reinforced lining. All work shall be done in strict accordance with the engineers drawings and specifications.

2. CONTRACTOR'S EXPERIENCE

2.1 Any contractor proposing to perform the work hereunder shall have demonstrated his ability to do the work by having successfully installed at least two million square feet of reinforced membrane lining.

3. LINING MATERIAL

3.1 The membrane used for lining material shall be fabric-reinforced CPER of new, first-quality products designed and manufactured specifically for the purpose of this work, and shall have been satisfactorily demonstrated by prior use to be suitable and durable for such purposes. The manufacturer shall have produced, and have in service in similar applications for a period of not less than one (1) year, at least two (2) million square feet of fabric-reinforced CPER material utilizing the same scrim specified for use under these specifications.

3.2 CPE utilized for encapsulation of the scrim shall be manufactured from a composition of high quality ingredients. Dusting agents of any kind are prohibited on the finished product.

3.3 Scrim used in the membrane shall be 10 × 10 1000d polyester of an open type weave that permits strike-through of the CPE through the fabric to facilitate adhesion between the plies of CPE. The fill yarn must have 2.5 turns per inch maximum and 2.0 turns per inch minimum. All selvage edges must be trimmed prior to applying the CPE coating.

3.4 The composite membrane material shall consist of a thoroughly bonded, fabric-reinforced CPE sheeting. It shall be manufactured by the calendering process and shall be uniform in color, thickness, size, and surface texture. The fabric shall be totally encapsulated between plies of CPE and shall not extend closer than 1/8 inch to the edge of the CPE coating either side of the fabric. Exposed fabric along longitudinal edges of roll stock and indications of delamination will not be permitted. The composite material shall be a flexible, durable, watertight product free of pinholes, blisters, holes, and contaminants and shall not delaminate in a water environment.

The composite membrane material shall be fabric-reinforced CPE consisting of one ply of scrim and two plies of CPE.

Property	Specification	Test Method
Thickness	.036, not less than .033	ASTM D-751
Tensile Strength, lbs., min.	200	ASTM D-751 Grab Method
Tongue Tear, lbs., min.	80	
Hydrostatic Resistance, psi, min.	250	ASTM D-751
Dimensional Stability		ASTM D-1204
(@ 160°F, 2 hrs.) % max. change	1.0	
(@ 212°F, 2 hrs.) % max. change	1.0	
Volatile Loss, % max.	0.2	ASTM D-1203 Method A
Low Temperature, Cold Bend, 1/8" mandrel for 4 hrs., °F	-25	ASTM D-2136
Ozone Resistance (3 ppm @ 30% strain @ 104 °F for 72 hrs.)	Pass	ASTM D-1149
Oil Resistance, Immersion Method, (ASTM No. 3 oil, 151 days @ 158 °F, max. wt. gain, %)	35.0	ASTM D-471
Ply Adhesion, Machine Method, 180° peel, lbs. /2" width, min.	16	ASTM D-412

3.5 The fabricator shall be an experienced firm customarily engaged in factory-fabricating individual widths of fabric-reinforced CPE roll stock into large sheets. Factory seams shall have a minimum of 1-½" scrim to scrim overlap when made by the solvent seaming method, and 5/8 inch scrim to scrim overlap when made by the heat welded method.

Each factory-fabricated sheet shall be given prominent, unique indelible identifying markings indicating proper direction of unrolling and/or unfolding to facilitate layout and positioning in the field. Each factory-fabricated sheet shall be individually packaged in a heavy cardboard or wooden crate fully enclosed and protected to prevent damage to it during shipment, prominently identified in the same fashion as the sheet within and showing the date of shipment. Until installed, factory-fabricated sheets shall be stored in their original unopened crates; if outdoors, they shall be stored on pallet and shall be potected from the direct rays of the sun under a light-colored heat-reflective opague cover in a manner that provides a free-flowing air space between the crate and cover.

4. OTHER MATERIALS

4.1 Solvent for cleaning contact surfaces of field joints and for other required uses shall be as recommended manufacturer or approved fabricator of the fabric-reinforced CPE

4.2 All seaming, sealing and high-solids adhesives shall be of a type or types recommended by the manufacturer or approved fabricator of the fabric-reinforced CPE and shall be delivered in original sealed containers.

5. INSTALLATION

5.1 Prior to ordering fabric-reinforced CPE material, the contractor may submit, for the engineer's approval, shop drawings showing lining sheet layout with proposed size, number, position, of all factory-fabricated sheets and indicating the location of all field joints. Shop drawings may also show complete details and/or methods for anchoring the lining at top of slope, making field joints, seals at structures, etc.

5.2 Lap joints shall be used to seal factory-fabricated sheets of fabric-reinforced CPE together in the field. All field joints between sheets of fabric-reinforced CPE shall be made on a supporting smooth surface and, unless the weather is sufficiently warm, heat guns shall be used to make the sealing temperature at least 90°F. The lap joints shall be formed by lapping the edges of sheets a minimum of 3" scrim-to-scrim. The contact surfaces of the sheets shall be wiped clean to remove all dirt, dust, moisture, or other foreign materials then wiped clean. Sufficient CPE-to-CPE bonding adhesive shall be applied to both contact surfaces in the joint area and the two surfaces pressed together while wet and immediately rolled. Any wrinkles shall be smoothed out and any cut edges of the fabric-reinforced CPE shall be sealed with a CPE adhesive to prevent wicking.

5.3 Any necessary repairs to the CPE membrane shall be patched with a piece of the membrane material itself and CPE-to-CPE adhesive. The adhesive shall be applied to the contact surfaces of both the patch and lining to be repaired, the two surfaces pressed together immediately and rolled, and any wrinkles smoothed out, all in accordance with Paragraph 5.2 hereof.

5.4 All joints, on completion of the work, shall be tightly bonded. Any membrane surface showing injury due to scuffing, penetration by foreign objects, or distress from other causes shall, as directed by the engineer, be replaced or repaired with an additional piece of fabric-reinforced CPE membrane of the proper size.

5.5 On completion of installation, the contractor shall dispose of all trash, waste, material and equipment used in connection with the work hereunder, and shall leave the premises in a neat and acceptable condition.

6. SEAM STRENGTH

6.1 All factory and field seams (joints) shall, after 12 days, have a seam strength of 170 pounds when tested in accordance with ASTM D-751, Grab Method (using 4" wide specimens having a length of 10" plus the seam width). The distance between the jaws of the testing apparatus at the start of the test must be 8" plus the seam width and shall have sufficient strength in peel that they fail by delamination from the scrim rather than in the plane of the seam.

CHEMICAL REAGENT DATA SHEET

OIL RESISTANT CPE & CPER

WATERSAVER DENVER
WATERSAVER CO INC [illegible] 5870 E. 56th Ave. [illegible]
[illegible] WATS 800 525 2424 [illegible]

REAGENTS	% SOLUTION	pH	PERCENT WEIGHT GAINS 70 HRS.	11 DAYS	81 DAYS
Acetic Acid	5	2.9	2.7	5.4	17.6
Acetone	100	2.4	44.0	43.5	40.4
Ammonium Hydroxide	10	12.1	4.7	9.6	34.7
Aniline	100	9.1	135.0	125.0	134.0
Benezene	100	10.9	dissolved	0	0
Carbon Tetrachloride	100	1.0	137.0	123.0	deteriorated
Citric acid	1	1.9	2.0	3.3	7.0
Cottonseed Oil	100	N/A	1.6	2.7	7.4
Detergent, Heavy Duty	0.025	10.5	2.0	3.6	12.0
Dimethylformamide	100	13.1	110.3	110.0	99.8
Ethyl alcohol	50	4.8	4.2	7.8	16.7
Ethyl acetate	100	8.1	75.5	68.5	dissolved
Ethyl dichloride	100	7.7	dissolved	0.	0.
Hexane	100	6.8	4.5	2.5	1.0
Hydrochloric Acid	10	1.3	1.8	3.0	7.4
Hydrogen Peroxide, 28%	3	3.5	1.3	3.0	10.3
Isooctane	100	10.4	2.3	2.0	0.6
Kerosene	100	4.0	11.6	13.0	12.4
Mineral Oil	100	N/A	0.4	- 0.04	- 0.9
Methyl Alcohol	100	6.4	2.0	2.6	- 0.3
Nitric Acid	40	.0	4.0	12.0	47.0
Nitric Acid	10	.5	1.7	3.0	15.5
Oleic Acid	100	1.8	2.0	3.8	6.2
Olive Oil	100	N/A	0.6	0.5	0.8
Phenol	5	6.0	13.3	22.6	29.0
Sodium Carbonate	20	11.2	1.8	2.4	2.2
Sodium Carbonate	2	11.6	2.0	3.2	6.4
Sodium Chloride	10	9.2	1.6	2.3	2.7
Sodium Hypochlorite	5	12.2	2.3	4.0	8.2
Sodium Hydroxide	60	8.3	0.7	1.0	0.7
Sodium Hydroxide	10	12.3	3.0	6.0	13.0
Sodium Hydroxide	1	12.5	3.0	8.0	15.6
Soap Solution	1	10.1	2.8	6.4	34.0
Sulfuric Acid	30	.7	0.1	0.8	0.5
Sulfuric Acid	3	1.5	1.4	2.8	6.7
Toluene	100	.7	dissolved	0	0
Transformer oil #55	100	N/A	3.6	6.5	12.8
Turpentine	100	4.6	30.6	31.0	30.7
Water - Distilled	100	5.0	2.0	3.4	10.6
Water - tap	100	7.6	2.0	3.5	10.7

Above tests are run under ASTM D 471, Immersion Method.
Weight gains are expressed in percent.
Tests were run at room temperature 75°F.

CPE/CPER-OR-CRDS:0282

CHEMICAL REAGENT DATA SHEET
OIL RESISTANT CPE & CPER

INSTALLATION PREPARATION GUIDE

WATERSAVER CO. INC. [illegible]
[illegible] WATS [illegible]

GENERAL INSTRUCTIONS FOR JOBSITE PREPARATION

1. The earth upon which the liner will be placed must be smooth and free from sharp rocks, roots, vegetation, and other foreign material. A compacted substrate is advisable to prevent settling. Compaction around pipes and structures is especially important.

2. Check measurements and grades prior to start of liner installation. Surveyor control stakes should be left in place to assist in placing the lining panels.

3. Dig the anchor trench as shown on the shop drawing or the engineering drawings. ALWAYS THROW EARTH FROM TRENCH AWAY FROM SIDE SLOPE.

4. Crew size will depend on the project size. A minimum of 6 men is required, most projects need at least 10 men to spread panels.

5. Sand bags will be needed to keep the material in position during windy conditions. Normally 20 sands bags per panel are required.

6. Tools and equipment not supplied by Watersaver include; wiping rags, paint brushes for adhesive, rakes and shovels. Liner panels may weigh as much as 4000#. A large front end loader or forklift will be required to assist in the spreading of the lining material. Palleted cartons are about 84" × 36" × 36".

7. Cements and adhesives shall be kept from extreme heat and cold.

8. A Technical Services Representative is available from the Watersaver Co. for a small fee when made part of the purchase agreement.

9. All PVC (Vinyl) liners must be covered with earth if an extended life is expected. A minimum of 12" of earth should be placed on the bottom and slopes. Side slopes of 3:1 or less are normally required to hold the earth cover. Windy conditions may require special rip rap considerations.

10. Driving on the liner is permitted only when the liner is first covered with 12" of earth. If an area is to have sustained traffic 24" of cover is advised. Damage to the liner must be repaired as it is discovered!

11. Structures including, pipes, splash pads, inlets, outlets, and headwalls should be finished prior to placement of the liner to structures.

This sheet is furnished to aid in planning liner installations. Watersaver Co., Inc. as a supplier of materials only, does not assume responsibility for errors in design, engineering, quantities, or dimensions.

APPENDIX E

LINER USERS

APPENDIX E-1

QUESTIONNAIRE TO LINER USERS

NOTE: For distribution refer
to Table 9.1 in report.

March 20, 1984 Our ref: 841-3015

RE: FLEXIBLE MEMBRANE LINERS AS LONG-TERM
BARRIERS FOR URANIUM MILL TAILINGS

Dear Sirs:

Golder Associates has been retained by Department of Supply and Services, Canada to conduct Phase I of an evaluation of flexible membrane liners for use as uranium tailings pond liners and dam membranes. The study is being carried out for Energy, Mines and Resources, Canada as part of the National Uranium Tailings Program.

Although the study will focus on liners for uranium tailings, information related to liner performance in the mining industry in general, as well as in the hazardous waste industry is also required.

Phase I of the study will be based on available published information, information from suppliers and information from industrial users. We understand that you currently have facilities in operation which utilize flexible membrane liners and we have therefore attached a questionnaire which we would like you to complete and return.

We are presently considering polymeric liners such as HDPE, HYPALON, CPE, PVC etc., as well as asphalt. Responses from industry users will be incorporated in the Phase I report.

... 2

The Phase I draft report is scheduled to be completed about April 1, 1984. Due to project timing constraints we would ask you to complete and return the attached questionnaire as soon as possible, preferably within two weeks.

Should you have any questions, please contact the undersigned in our London, Ontario office.

Yours truly

GOLDER ASSOCIATES

Frederick W. Firlotte, P. Eng.

FWF/jl
Att.

INDUSTRY USER QUESTIONNAIRE

1. Location of Facility: ______________________

2. Dimensions of Facility (area and depth): __________
____

3. Year and Month(s) Liner Installed: __________
____

4. Designer (Consultant): ______________________

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
____

6. Liner Supplier: ______________________

7. Liner Manufacturer: ______________________

8. Liner Installer: ______________________

9. Liner Thickness: ______________________

10. Liner Reinforcement/Scrim (if applicable) __________
____

11. Thickness and Type of Soil Cover over Liner: (if applicable)
____

12. Nature of Material/Waste Retained by Liner: __________
____

Physical Properties: (grain size distribution, water content, etc.)
____
____

Chemical Properties/Composition: __________
____
____

13. Describe site preparation prior to liner placement:

14. Is liner installation considered successful? _________

Describe nature of liner defects (if any; if known):

15. Describe any problems related to liner installation or operation of facility which might be liner related:

16. Was a monitoring system installed at the facility?

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

17. Was there any follow-up work carried out to evaluate performance of liner system? ____________________

If so, briefly describe liner performance: (attach published case histories if available)

____

____

____

____

____

____

APPENDIX E-2

COMPLETED USER QUESTIONNAIRES

INDUSTRY USER QUESTIONNAIRE

Cotter Corporation

1. Location of Facility: 2 miles south of Canon City, Colorado Sec. 16, T.19S., R.70W., 6th P.M., Fremont County, CO

2. Dimensions of Facility (area and depth): Approximately 150 Acres - Stage 1 approximately 100 feet.

3. Year and Month(s) Liner Installed: 1978

4. Designer (Consultant): Attn: Mr. Forrest Gifford Wahler Associates, Palo Alto, California

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   1.5 ft. compacted clay subliner overlain with Hypalon.

6. Liner Supplier: Watersavers, Inc., Denver, Colorado

7. Liner Manufacturer: DuPont

8. Liner Installer: Wahler Associates/Hovater Way Engineers/ Stafford Constr.

9. Liner Thickness: 36, 45 and 60 mil

10. Liner Reinforcement/Scrim (if applicable) Yes, but information about scrim pattern not readily available.

11. Thickness and Type of Soil Cover over Liner: (if applicable)

    2 - 3 feet on shallow slopes.

12. Nature of Material/Waste Retained by Liner: Low pH uranium mill tailings

    Physical Properties: (grain size distribution, water content, etc.)

    Approximately 30% solids, 200 mesh

    Chemical Properties/Composition: Ore is leached using sulphuric acid. Nominal pH in pond is 4, however, samples indicate pH has been as low as 2 in some areas, at times.

Cotter Corporation (cont'd)

13. Describe site preparation prior to liner placement:

Site overburden removed to bedrock. Fractures in bedrock grouted. System underdrain system installed (See item 16, below). Eighteen inch compacted clay subliner installed. Hypalon installed over clay.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

Please see response to Item 15, below.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

None noted. For further information, please contact former project manager - Mr. Ambrose McCready, Lawson Associates (714) 838-7992

16. Was a monitoring system installed at the facility?

Yes

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

The "Monitoring System" is a system underdrain designed to relieve hydrostatic pressure due to spring flow beneath impoundment. Data indicate no change in water quality or flow rates relative to pre-milling condition.

Cotter Corporation (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? Yes

If so, briefly describe liner performance: (attach published case histories if available)

Literature searches indicate Hypalon resistance to lengthy (i.e., 15 year)

exposure to ultra violet light and low pH (i.e., greater than pH of 1.0)

GOLDER ASSOCIATES
MAR 25 1984
RECEIVED — LONDON

INDUSTRY USER QUESTIONNAIRE

Minerals Exploration

1. Location of Facility: Sweetwater Co., Wyoming

2. Dimensions of Facility (area and depth): 60 ACRES
100 FEET DEEP 3:1 (H:V) SLOPES

3. Year and Month(s) Liner Installed: AUGUST-SEPTEMBER 1980

4. Designer (Consultant): DAMES + MOORE

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
Hypalon side slopes, PVC bottom

6. Liner Supplier: WATERSAVER

7. Liner Manufacturer: STEVENS

8. Liner Installer: CRESTLINE

9. Liner Thickness: 20 mil PVC BOTTOM, 30 mil HYPALON SIDES

10. Liner Reinforcement/Scrim (if applicable) NONE

11. Thickness and Type of Soil Cover over Liner: (if applicable)
None

12. Nature of Material/Waste Retained by Liner:
Uranium Mill Tailings

Physical Properties: (grain size distribution, water content, etc.)
uniform sand slurry

Chemical Properties/Composition:
acidic pH >2.0
high TDS

Minerals Exploration (cont'd)

13. Describe site preparation prior to liner placement:

EXCAVATED ≈ 50 FOOT SUBSURFACE, BUILT ≈ 50 FOOT RETENTION STRUCTURE, INSTALLED SUBDRAIN MONITOR SYSTEM, BLADED BOTTOM AND SIDES TO REMOVE ROCKS

14. Is liner installation considered successful? yes

Describe nature of liner defects (if any; if known):

mechanical damage from equipment, wind damage, and wave driven debris

15. Describe any problems related to liner installation or operation of facility which might be liner related:

PATCHING OF LINER REQUIRED DUE TO WAVE ACTION AND DEBRIS.

EXCESIVE WINDS HAVE CAUSED DAMAGE. SOLUTION WAS TO ADD VENTS AND ADDITIONAL SAND SACKS

16. Was a monitoring system installed at the facility?

YES SUBDRAIN MONITOR SYSTEM MONITOR WELL OUTSIDE CELL

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

NONE DETECTED TO DATE

Minerals Exploration (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? ____________

If so, briefly describe liner performance: (attach published case histories if available)

____

____

____

____

____

____

INDUSTRY USER QUESTIONNAIRE

DENISON MINES

1. Location of Facility: Dam No. 1, Williams Lake

2. Dimensions of Facility (area and depth): 28,000 ft^2

3. Year and Month(s) Liner Installed:
1979

4. Designer (Consultant): Golder Associates

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
Laminated hydrocarbon resistent PVC

6. Liner Supplier: Synflex Industries

7. Liner Manufacturer:

8. Liner Installer:

9. Liner Thickness: 0.045 inches

10. Liner Reinforcement/Scrim (if applicable)

11. Thickness and Type of Soil Cover over Liner: (if applicable)
0.3 metres of bedding sand below the above liner

12. Nature of Material/Waste Retained by Liner:
Inactive Uranium Tailings

Physical Properties: (grain size distribution, water content, etc.)

Chemical Properties/Composition:

Denison Mines (cont'd)

13. Describe site preparation prior to liner placement:

The membrane was fastened to a specially designed anchor beam

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

15. Describe any problems related to liner installation or operation of facility which might be liner related:

16. Was a monitoring system installed at the facility?

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

GOLDER ASSOCIATES
MAR 27 1984
RECEIVED – LONDON

INDUSTRY USER QUESTIONNAIRE

Dawn Mining Company

1. Location of Facility: FORD, Washington

2. Dimensions of Facility (area and depth):
65' deep X 28 acres top a[illegible]

3. Year and Month(s) Liner Installed:
august 1981

4. Designer (Consultant):

5. Liner Type (i.e. Hypalon, [✓ HDPE], asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)

6. Liner Supplier: Universal Linings

7. Liner Manufacturer: Gundel Plastics

8. Liner Installer: Universal Linings

9. Liner Thickness: 30 mil

10. Liner Reinforcement/Scrim (if applicable)
—

11. Thickness and Type of Soil Cover over Liner: (if applicable)
2' fine sand

12. Nature of Material/Waste Retained by Liner:
Uranium Tailings

Physical Properties: (grain size distribution, water content, etc.)

Chemical Properties/Composition:
Typical acid Leach Tailings
pH ~1.8

Dawn Mining Company

13. Describe site preparation prior to liner placement:

Liner was laid on a bed of lightly compacted fine sand about 6 inches thick.

14. Is liner installation considered successful?

Describe nature of liner defects (if any; if known):

yes

15. Describe any problems related to liner installation or operation of facility which might be liner related:

3:1 slope proved to much for sand cover (which had to high a clay content) during periods of high precipitation and snow melt, causing areas of cover to slide, exposing liner, but no damage.

16. Was a monitoring system installed at the facility?

yes.

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Suction Lysimeters were installed at bottom elevation of pond. These produce from a few milliliters to half a liter of sample.

Dawn Mining Company

17. Was there any follow-up work carried out to evaluate performance of liner system? No

If so, briefly describe liner performance: (attach published case histories if available)

INDUSTRY USER QUESTIONNAIRE Rio Algom

Panel uranium mine, Elliot Lake, Ontario. Liners installed in dams A, B, D, F, settling ponds L1 and L2 downstream of treatment plant.

1. Location of Facility: Strike Lake Tailings Area.

2. Dimensions of Facility (area and depth):
PONDS L1 = 3 acres
L2 = 4.2 acres
DAMS A length = 600 ft. depth = 42 ft. B length = 390 ft depth = 70 ft D length = 190 ft depth = 49 ft F length = 810 f depth = 28 f
from foundation level

3. Year and Month(s) Liner Installed: 1978 September and October
1979 May, June, July, August

4. Designer (Consultant): Golder Associates

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)
Hypalon

6. Liner Supplier: Dunline (Sept. 1978) and Synflex Industries (Nov. 1978 & 197

7. Liner Manufacturer: Dunline and Synflex Industries Inc.

8. Liner Installer: Romm Const. Company under supervision of personnel from Dunline and Synflex Industries Inc.

9. Liner Thickness: 0.030 inches. 33 feet wide panels

10. Liner Reinforcement/Scrim (if applicable) 0.045 inches thick liner for sections of ponds above water surface.

11. Thickness and Type of Soil Cover over Liner: (if applicable) Liners installed on and covered with A bedding sand layer 2 ft. in thickness for dams B & D. Liners drapped against concrete cut-off wall and A 2ft thick chimney layer of sand placed against liner for dams A & F, Liners placed on 2' thick bedding sand layer at bottom of ponds L1 & L2. Liners in dams were incorporate into the till core.

12. Nature of Material/Waste Retained by Liner:
Treated uranium tailings effluent in ponds.

Physical Properties: (grain size distribution, water content, etc.)

Chemical Properties/Composition:

Rio Algom (cont'd)

13. Describe site preparation prior to liner placement:

Ponds: excavated to bedrock. Granular material foundation over rock with 2 feet thick bedding sand layer under liner dams A, F: Liner placed against concrete cut-off wall. Upstream side of liner protected to 2 feet thick layer of bedding sand. Dams D and B: Liner placed on and covered with 2 foot thick layer of bedding sand. Dams A,F. Liner anchored at base of wall with fill concrete and drapped over wall. Dams B & D: 4 inch deep slot and rubber plugs anchor membrane into concrete beam.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

Pin holes required field patching

One batch of membrane cement was of poor quality.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Wet weath required tent over sections being welded

Must be free of oil, water, grease and requires heat to weld panel.

Initial slot design of 3 inch had to be increased to 4 inch rubber plugs

Were to stiff to be stretched into the slop and had to hammered in.

16. Was a monitoring system installed at the facility?

Yes, sampling wells installed downstream of Dam A and in pond berms to monitor seepage.

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Information retained by Rio Algom Limited

Rio Algom (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? Not by Golder Associates

If so, briefly describe liner performance: (attach published case histories if available)

INDUSTRY USER QUESTIONNAIRE

WESTERN NUCLEAR INC.

1. Location of Facility: Spokane Indian Reservation, Washington, USA

2. Dimensions of Facility (area and depth): currently covers approcimately 90 acres, current maximum depth, approximately 65 feet.

3. Year and Month(s) Liner Installed: Original installed in 1977, additions in 1979. 1st use in May, 1978.

4. Designer (Consultant): Dravo Engineers

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   Reinforced Hypalon

6. Liner Supplier: B.F. Goodrich

7. Liner Manufacturer: B.F. Goodrich

8. Liner Installer: B.F. Goodrich supervised

9. Liner Thickness: 30 mil

10. Liner Reinforcement/Scrim (if applicable) nylon

11. Thickness and Type of Soil Cover over Liner: (if applicable)

    12-inches select sand

12. Nature of Material/Waste Retained by Liner:

    Uranium mill tailings

    Physical Properties: (grain size distribution, water content, etc.)

    Top size = 20 mesh - 55% + 150 mesh slurry discharged at approximately 45 - 50% solids, in-place up to about 90 lb. dry solids per cu. ft.

    Chemical Properties/Composition: Solids mostly quartz type material; solution high in Ca and SO_4 + with pH ranging from 5 to 9.

Western Nuclear, Inc. (cont'd)

13. Describe site preparation prior to liner placement:

Area grubbed, topsoil removed, then area excavated to grade on clean sand. Any basement rock exposed is covered by suitable sandy material.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

None known

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Liner can be punctured if sufficient care is not taken. This is probably true with all liners.

16. Was a monitoring system installed at the facility?

Yes

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Monitor wells were placed into basement rock both upgradient and downgradient from the impoundment area. To-date, anomolies in the sampling data do not appear to be liner related. Radionuclides have not been present.

Western Nuclear Inc. (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? **Not per se**

If so, briefly describe liner performance: (attach published case histories if available)

Monitorning of the groundwater regime is an ongoing evaluation of the lined pond.

INDUSTRY USER QUESTIONNAIRE

DENISON MINES

1. Location of Facility: Dam 10, Denison Mines Tailings, Management Area, Elliot Lake, Ontario

2. Dimensions of Facility (area and depth):

   75 Hectares, presently 25 metres

3. Year and Month(s) Liner Installed:

   Initial installation, 1971-72, men raised annually since 1977.

4. Designer (Consultant): Golder Associates

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   Hypalon

6. Liner Supplier: Several, initially Dunlop Industries, then later Synflex Industries

7. Liner Manufacturer: Calendered in Dunlop's Plant in Southern Ont.

8. Liner Installer: Reema tip top to 1981, since then Denison's own forces. Supervised by supplier

9. Liner Thickness: 0.030 inches

10. Liner Reinforcement/Scrim (if applicable)

    None

11. Thickness and Type of Soil Cover over Liner: (if applicable)

12. Nature of Material/Waste Retained by Liner:

    Uranium Tailings

    Physical Properties: (grain size distribution, water content, etc.)

    Silt sized tailings 50-80 per cent water content

    Chemical Properties/Composition:

DENISON MINES (cont'd)

13. Describe site preparation prior to liner placement:

Hypalon liner is attached to anchor beam on bedrock abutments. Upstream toe of dam is located on very thick granular deposits. The liner was weighted and sunk against the upstream force of the dam.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

Not known

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Liner slopes at 1:5 - 1:0, new upstream force. Stability of upstream shell on steeply sloping liner due to reduced angle of internal friction sand/hypalon (approx. 20 degrees) has been of concern.

16. Was a monitoring system installed at the facility?

Yes. Downstream toe monitoring system

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

INDUSTRY USER QUESTIONNAIRE

INCO

1. Location of Facility: COPPER CLIFF, ONT.

2. Dimensions of Facility (area and depth):
   37,500 sq.ft. Max. depth 3.5 ft.

3. Year and Month(s) Liner Installed: 1977

4. Designer (Consultant): INCO. ENGINEERING

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)
   C.P.E.

6. Liner Supplier:

7. Liner Manufacturer:

8. Liner Installer: CONTRACTOR TO INCO

9. Liner Thickness: 30 MIL

10. Liner Reinforcement/Scrim (if applicable)
    —

11. Thickness and Type of Soil Cover over Liner: (if applicable)
    1 FT. of 2" CRUSHED STONE

12. Nature of Material/Waste Retained by Liner:
    TAILINGS SEEPAGE WATER

    Physical Properties: (grain size distribution, water content, etc.)
    SUSPENDED SOLIDS 50 Mg./l

    Chemical Properties/Composition:
    Typical Characteristics: pH 3.1
    Nickel 15 mg/l Iron 250 mg/l

Inco (cont'd)

13. Describe site preparation prior to liner placement:

As per attached Section of Dyke.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

15. Describe any problems related to liner installation or operation of facility which might be liner related:

—

16. Was a monitoring system installed at the facility?

No

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

The pond was inspected daily to ensure that there was no overflow, but no inspection was made with regards to seepage through the liner.

Inco (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? No.

    If so, briefly describe liner performance: (attach published case histories if available)

March 1, 1984
841-3015
FWF/jl

INDUSTRY USER QUESTIONNAIRE

Potash Corp. of Saskatchewan

1. Location of Facility: PCS Mining LTD - Rocanville Division.
2. Dimensions of Facility (area and depth): 1340' Long x 640 wide x 17' deep
3. Year and Month(s) Liner Installed: Started Oct 82 - completed and final inspection June 1983
4. Designer (Consultant): PCS Design Engineering
5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   HDPE
6. Liner Supplier: Synflex Industries Inc (now Gundle Lining Systems Ltd ~~Now Gundle of Canada~~)
7. Liner Manufacturer: Gundle Lining Systems
8. Liner Installer: Synflex Industries Inc
9. Liner Thickness: Bottom 30 mil - Slopes 60 mil
10. Liner Reinforcement/Scrim (if applicable) —
11. Thickness and Type of Soil Cover over Liner: (if applicable)

    No cover
12. Nature of Material/Waste Retained by Liner:

    Brine - saturated with NACL and KCL.

    Physical Properties: (grain size distribution, water content, etc.)

    Chemical Properties/Composition:

Potash Corp. of Saskatchewan (cont'd)

13. Describe site preparation prior to liner placement:

Dikes were built around area to be lined. Inside slope of dikes are 3-1. Bottom of area and slopes of dikes were then covered with 6" of sand. Sand was roller packed.

14. Is liner installation considered successful? yes.

Describe nature of liner defects (if any; if known):

Would not recommend using 30 mil material again. Very difficult to weld without melting through. Also easily holed.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Liner cannot be installed in cold weather - wet weather or during high winds.

16. Was a monitoring system installed at the facility?

Ditch system at a lower elevation than pond bottom goes right around the outside of the lined area.

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Have brine in the pond - but have found no indication of seepage into the ditch system.

Potash Corp. of Saskatchewan (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? yes.

If so, briefly describe liner performance: (attach published case histories if available)

Mixed Intracid Rhodamine WT liquid Dye in a 20% solution with about 3' of brine in the pond. Monitored ditch system - found no indication of the dye in the ditch water.

INDUSTRY USER QUESTIONNAIRE

Falconbridge Mines

1. Location of Facility: FALCONBRIDGE ONTARIO

2. Dimensions of Facility (area and depth):
DAM LENGTH 950 FT DEPTH AVE 25 FT.

3. Year and Month(s) Liner Installed:
AUGUST 1978

4. Designer (Consultant): GEOCON

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
30MIL PVC LINER

6. Liner Supplier: STAFF INDUSTRIES.

7. Liner Manufacturer: " "

8. Liner Installer: PITTS ENGINEERING CONSTRUCTION

9. Liner Thickness: 30 MIL

10. Liner Reinforcement/Scrim (if applicable)

11. Thickness and Type of Soil Cover over Liner: (if applicable)
12" SAND COVER PLUS 12" COARSE SLAG

12. Nature of Material/Waste Retained by Liner:
TAILINGS WASTE FROM OUR MILL

Physical Properties: (grain size distribution, water content, etc.)

Chemical Properties/Composition:

Falconbridge Mines (cont'd)

13. Describe site preparation prior to liner placement:

REMOVAL APPROX 5 FT OF SWAMP
DOWN TO CLAY - BUILDING OF LOW
DAMS TO ALLOW FOR DEWATERING
PRIOR TO START OF MAIN DAM CONSTN

14. Is liner installation considered successful? YES

Describe nature of liner defects (if any; if known):

15. Describe any problems related to liner installation or operation of facility which might be liner related:

16. Was a monitoring system installed at the facility?

Yes initially during Construction

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

NO ABNORMAL WATER SEEPAGE
SEE GEOCON FOR FURTHER INFO
SUDBURY ONT - G CLAUSEN

Falconbridge Mines (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? No

If so, briefly describe liner performance: (attach published case histories if available)

INDUSTRY USER QUESTIONNAIRE

Central Canada Potash

1. Location of Facility: Central Canada Potash - tailings area
PO Box 1500, Colonsay, Saskatchewan SOK 0Z0

2. Dimensions of Facility (area and depth): In 4 sections of tailings and brine pond dyke to prevent brine migration through compacted glacial till

3. Year and Month(s) Liner Installed: Fall, 1981; Summer - 1982

4. Designer (Consultant): Kilborn (Saskatchewan) Ltd.

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

2 types: 30 mil Hypalon, 30 mil Chlorinated Polyethylene

6. Liner Supplier: Synflex Industries Inc.

7. Liner Manufacturer: Hypalon - Polymer Dupont, Membrane Dunlop
Polyethylene - Mfgr Synflex, Resin Supply Canadian General Tower

8. Liner Installer: Brodsky Construction, Saskatoon
Seaming by Synflex Group

9. Liner Thickness: 30 mil

10. Liner Reinforcement/Scrim (if applicable) None

11. Thickness and Type of Soil Cover over Liner: (if applicable)

See Item 13

12. Nature of Material/Waste Retained by Liner:

Solid salt and sodium chloride brine

Physical Properties: (grain size distribution, water content, etc.)

Variable grain size - all —20 mesh down to clay particles likely, -10*mesh liner is to prevent liquid migration - saturated (or nearly so) sodium chloride brine.

Chemical Properties/Composition:

NaCl 200,000 ppm, balance H_2O

* micron

Central Canada Potash (cont'd)

13. Describe site preparation prior to liner placement:

Construct compacted till dyke with smoothed inside face. 3:1 slope. Compacted 6" fine sand under liner. 1' compacted fine sand over liner. Finished with 1 to 2' of riprap, where required for wave action protection.

14. Is liner installation considered successful? Yes (See Below)

Describe nature of liner defects (if any; if known):

Don't know yet, will take some years to find out.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

None of any account to date.

16. Was a monitoring system installed at the facility?

Yes but not to monitor liner performance per se monitors overall tails area behaviour.

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

No information of use to date. No change in background water quality levels.

Central Canada Potash (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? Not yet.

If so, briefly describe liner performance: (attach published case histories if available)

Please note that the liner used here is not a pool or pond type. It is a strip type installed in various compacted till dykes to prevent essentially horizontal migration of brine through the dyke itself. The liner installation will also tend to increase the length of any potential flow path under the dykes to the line areas.

INDUSTRY USER QUESTIONNAIRE

Potash Corp. of Saskatchewan Mining Limited

1. Location of Facility: CORY MINE - 500 FT FROM MILL
2. Dimensions of Facility (area and depth): 235' X 230' X 16 FT DEEP.
3. Year and Month(s) Liner Installed: JULY & AUGUST 1976
4. Designer (Consultant): B.B. TORCHINSKY - DUNLINE LIMITED
5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   DUNSEAL HYPALON LINER
6. Liner Supplier: DUNLINE LTD - DUNCOP - TORONTO.
7. Liner Manufacturer: SAME
8. Liner Installer: DUVAL EMPLOYEES - SUPERVISION DUNLINE
9. Liner Thickness: 0.030"
10. Liner Reinforcement/Scrim (if applicable) NONE
11. Thickness and Type of Soil Cover over Liner: (if applicable)

    NONE -
12. Nature of Material/Waste Retained by Liner:

    SATURATED BRINE

    Physical Properties: (grain size distribution, water content, etc.)

    —

    Chemical Properties/Composition:

    —

Potash Corp. of Saskatchewan Mining Limited (cont'd)

13. Describe site preparation prior to liner placement:

-OLD LINER WAS NONE EXISTANT - ALL SATURATED SOIL HAD TO BE REMOVED & NEW TIL BROUGHT IN AND FORMED - PREPARATION OF BASE WAS SMOOTH PACKED TIL WITH NO LUMPS OR STONES

14. Is liner installation considered successful? YES

Describe nature of liner defects (if any; if known):

- FEW AIR BUBBLES WHEN FIRST INSTALLED THAT RUPTURED & HAD TO BE PATCHED - NOT A DEFECT. - BUBBLES HAD TO BE WALKED OUT WHILE FILLING

15. Describe any problems related to liner installation or operation of facility which might be liner related:

- INSTALLATION WENT SMOOTHLY EXCEPT THE FASTENING OF THE LINER TO THE CONCRETE INLET/SUCTION

16. Was a monitoring system installed at the facility?

NO - VISUAL INSPECTIONS HAVE TO BE DONE

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Potash Corp. of Saskatchewan Mining Limited (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? YES.

If so, briefly describe liner performance: (attach published case histories if available)

-LINER WAS CLOSELY INSPECTED THE FIRST
COUPLE YEARS FOR LEAKAGE & PLYABILITY.
-AFEW PATCHES WERE PUT ON & THE MEMBRANE
RETAINED IT'S PLYABILITY.
-SINCE 1978 NO REAL INSPECTIONS OR
WORK HAS BEEN REQUIRED.

IF YOU HAVE ANY QUESTIONS ABOUT THE INSTALLATION I AM AVAILABLE

INDUSTRY USER QUESTIONNAIRE

Public Service Company of Colorado

1. Location of Facility: Pawnee Station, Brush, Colorado

2. Dimensions of Facility (area and depth): 8 ponds - total area approximately 2,874,442 sq. ft. (65.9 acres). Avg depth 10'-12'

3. Year and Month(s) Liner Installed: 1979 & 1980

4. Designer (Consultant): Stearns-Roger Inc.

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.) (if asphalt, indicate if sprayed or concrete)

   HDPE

6. Liner Supplier: Schlegel Area Sealing Systems

7. Liner Manufacturer: Schlegel Area Sealing Systems

8. Liner Installer: Schlegel Area Sealing Systems

9. Liner Thickness: 80 mils

10. Liner Reinforcement/Scrim (if applicable)

11. Thickness and Type of Soil Cover over Liner: (if applicable)

    1' of sand on bottom to prevent lifting by wind while dry

12. Nature of Material/Waste Retained by Liner: Processed water, bottom ash from boiler

    Physical Properties: (grain size distribution, water content, etc.)

    Chemical Properties/Composition: All mixed salt: pH: 5.0-11.0, TDS: 1000 - 2000,000 mgle, Na+: 100-80,000 mgle; Cl^-:100-80,000 mgle; Ca++:0-$CaSO_4$ saturation

Public Service Company of Colorado (cont'd)

13. Describe site preparation prior to liner placement:

Approximately 2' clay liner, rolled with steel drum, hand removed a remaining sharp objects, dressed any rough areas by hand raking just prior to unrolling liner.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

None

15. Describe any problems related to liner installation or operation of facility which might be liner related:

None

16. Was a monitoring system installed at the facility?

Yes - 7 monitoring wells around perimeter of site

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Have not detected any evidence of any leakage. Wells are checked on a monthly basis.

Public Service Company of Colorado (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? ______________

If so, briefly describe liner performance: (attach published case histories if available)

All seams were inspected and ultrasonically tested.

Sample attached.

INDUSTRY USER QUESTIONNAIRE

Chevron Canada Resources Limited

1. Location of Facility: Fort Saskatchewan, Alberta

2. Dimensions of Facility (area and depth):

318 m long x 133m wide x 10 m deep

3. Year and Month(s) Liner Installed:

July 1982

4. Designer (Consultant): EBA Engineering Consultants Ltd.

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)

HDPE

6. Liner Supplier: SchLegel Lining Technology Inc.

7. Liner Manufacturer: SchLegel Lining Technology Inc.

8. Liner Installer: SchLegel Lining Technology Inc.

9. Liner Thickness 60 mils

10. Liner Reinforcement/Scrim (if applicable) N/A

11. Thickness and Type of Soil Cover over Liner: (if applicable)

None

12. Nature of Material/Waste Retained by Liner:

Brine

Physical Properties: (grain size distribution, water content, etc.)

Specific Gravity @ °C - 1.18

Chemical Properties/Composition:

Refer to properties of pure brine.

Chevron Canada Resources Limited

13. Describe site preparation prior to liner placement:

The liner was installed on an existing brine pond.

The original clay liner was repaired and an underdrain system,

consisting of clean sand and perforated pipes, was installed.

The flexible liner was placed above the underdrain system.

14. Is liner installation considered successful? Yes

Describe nature of liner defects (if any; if known):

N/A

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Installation of this type of liner is labor intensive and highly

dependant on favourable weather conditions.

16. Was a monitoring system installed at the facility?

Yes

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Information inconclusive at this time.

INDUSTRY USER QUESTIONNAIRE

Allied Chemical Limited

1. Location of Facility: Allied Chemical Canada, Amherstburg, Ont.

2. Dimensions of Facility (area and depth): 4 Ponds,
Base - 185' x 230', Top - 275' x 320', Height - 15'

3. Year and Month(s) Liner Installed: (1) 1966, (2 & 3) Spring
1974, (4) Summer 1977

4. Designer (Consultant): (1) Giffels Assoc. (2,3,4) Carr & Donald Assoc.

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
(1) Royal Seal E.P.D.M., (2 - 4) E.P.D.M.

6. Liner Supplier: (1)
(2 & 3) Water Guidance Systems Inc., (4) Lexsuco Canada

7. Liner Manufacturer: (1) U.S. Rubber Co., (2 - 4) Uniroyal Co.

8. Liner Installer: (1) Supplier
(2 & 3) Supplier, (4) Supplier & L. Bondy Excavating

9. Liner Thickness: (1) 0.058", (2 & 3) 1/16", (4) 50 mil.

10. Liner Reinforcement/Scrim (if applicable) -

11. Thickness and Type of Soil Cover over Liner: (if applicable)
-

12. Nature of Material/Waste Retained by Liner: Liquid
Calcium Chloride

Physical Properties: (grain size distribution, water content, etc.)
-

Chemical Properties/Composition: 35% Ca. Cl.

Allied Chemical Limited (cont'd)

13. Describe site preparation prior to liner placement:

The sites were stripped of all topsoil, fill and debris material. The base of pond 4 was scarified and recompacted. The berms of all ponds were constructed using a imported silty clay material placed and compacted to between 95 and 100 per cent Standard Proctor. Prior to placing the liner in pond 1, the subgrade was hand raked to remove all loose earth, (Over)

14. Is liner installation considered successful? ________

Describe nature of liner defects (if any; if known):

The compacted clay/rubber liner system is operating successfully, however, the liners themselves could not be considered successful. Most of the problems with the liners occur at the seams where loss of bond between two sheets is a continuing problem. Further, problems have also been encountered where patching of rips or tears have been carried out. (Over)

15. Describe any problems related to liner installation or operation of facility which might be liner related:

Installation of the rubber liner should be carried out by qualified personnel. Installations carried out by suppliers were quite smooth and followed contours of pond very well. Work done by untrained personnel, however, resulted in nonuniform finished product, with folds and pockets etc. in the finished liner.

16. Was a monitoring system installed at the facility?

No

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

13. rocks, and cobbles, etc. Prior to placing the liner for ponds 2 to 4, inclusive, a layer of fine sand several inches thick was placed on the subgrade.

14. On the oldest liner slight surficial cracking of the liner material or deterioration of the material is evident in some areas. This is believed due to aging and was called "ozone depletion of the plasticizers" by one of the suppliers.

Allied Chemical Limited (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? No

If so, briefly describe liner performance: (attach published case histories if available)

INDUSTRY USER QUESTIONNAIRE

Allied Chemical Limited

1. Location of Facility: Allied Chemical Canada, Amherstburg, Ont.

2. Dimensions of Facility (area and depth): Base - 185' x 230', Top - 275' x 320', Height 15'

3. Year and Month(s) Liner Installed: (5) August 1981

4. Designer (Consultant): (5) Allied Chemical

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)
(5) Asphaltic Concrete and sprayed

6. Liner Supplier: (5) A.A.P.C.O. Asphalting

7. Liner Manufacturer: (5) A.A.P.C.O. Asphalting

8. Liner Installer: (5) E. Bondy Trucking

9. Liner Thickness: (5) 3 Inches

10. Liner Reinforcement/Scrim (if applicable) -

11. Thickness and Type of Soil Cover over Liner: (if applicable)
-

12. Nature of Material/Waste Retained by Liner: Liquid Calcium Chloride

Physical Properties: (grain size distribution, water content, etc.)
-

Chemical Properties/Composition: 35% Ca. Cl.

Allied Chemical Limited (cont'd)

13. Describe site preparation prior to liner placement:

The site was stripped of all topsoil, fill and debris material and the base was scarified and recompacted. Prior to placing the asphaltic concrete a 6 inch thick layer of Granular 'A' was placed within the pond. Following placement of the asphaltic concrete the surface was sprayed with a liquid asphalt sealer.

14. Is liner installation considered successful? ________

Describe nature of liner defects (if any; if known):

The asphalt liner has performed satisfactorily to date. Some slight drying and or cracking of the liquid asphalt has been noted but it is proposed to reapply the liquid asphalt at regular intervals to offset this slight deterioration. A routine maintenance program of spraying every 3 to 5 years is being undertaken.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

During placement problems were had with compaction of the rich asphaltic mixture on the 3 to 1 slopes of the pond. Tearing of the material occurred and required removal and replacement on several occasions. Asphaltic mixutre should be designed to achieve minimum air voids content under minimum compactive effort.

16. Was a monitoring system installed at the facility?

No

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

Allied Chemcial Limited (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? No

If so, briefly describe liner performance: (attach published case histories if available)

INDUSTRY USER QUESTIONNAIRE

Dome Petroleum

1. Location of Facility: KERROBERT, SASKATCHEWAN SW 1/4-34-33-22 W3

2. Dimensions of Facility (area and depth): 600m ^{2} BOTTOM X 5M HIGH

3. Year and Month(s) Liner Installed: SEPTEMBER 1983

4. Designer (Consultant): DOME IN-HOUSE - A. WONG

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)

PVC

6. Liner Supplier: NILOS CANADA LTD. OF EDMONTON

7. Liner Manufacturer: CANADIAN GENERAL TOWER OF ONTARIO

8. Liner Installer: KENGO CONSTRUCTION & EQUIPMENT LTD.

9. Liner Thickness: 20 MIL

10. Liner Reinforcement/Scrim (if applicable) N/A

11. Thickness and Type of Soil Cover over Liner: (if applicable)

305 mm SAND

12. Nature of Material/Waste Retained by Liner:

BRINE - FROM NATURAL GAS LIQUIDS STORAGE CAVERNS

Physical Properties: (grain size distribution, water content, etc.)

BRINE - SOME HYDROCARBON CONTENT

Chemical Properties/Composition: BRINE

13. Describe site preparation prior to liner placement:

1. PIT BOTTOM CUT TO SOLID SOIL

2. BUILD BACK UP WITH CLAY COMPACTED TO 97% M.P.D.

3. PLACE BEDDING SAND 50 mm THICK.

4. LINER ANCHORED IN A TRENCH BENEATH A COMPACTED CLAY BERM. CLAY DYKES WERE NOT LINED AND HAVE 3 TO 1 INTERIOR SLOPE.

14. Is liner installation considered successful? YES

Describe nature of liner defects (if any; if known):

NONE

15. Describe any problems related to liner installation or operation of facility which might be liner related:

CARE SHOULD BE TAKEN TO PREVENT ADHESIVE FROM DEGRADATION DUE TO EXCESSIVE EXPOSURE, PARTICULARLY IN HOT WEATHER.

16. Was a monitoring system installed at the facility?

YES

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

28 MONITOR WELLS INSTALLED TO MONITOR THIS NEW PIT AND AN EXISTING ADJACENT PIT. 7 AROUND TOP OF THE DYKES AND BALANCE IN AREA SURROUNDING PIT. ALL WELLS SAMPLED BI-MONTHLY, AND SENT TO INDEPENDENT HYDROLOGIST FOR ANALYSING.

Dome Petroleum (cont'd)

17. Was there any follow-up work carried out to evaluate performance of liner system? YES

If so, briefly describe liner performance: (attach published case histories if available)

ALL WELLS TO BE SAMPLED MONTHLY FOR THE FIRST 6 UNFROZEN MONTHS OF 1984.

INDUSTRY USER QUESTIONNAIRE

Dome Petroleum

1. Location of Facility: N1/2-14-55-22-W4M, FORT SASKATCHEWAN, ALBERTA

2. Dimensions of Facility (area and depth): DEPTH - 23'-0"

NORTHSIDE-621.83', EASTSIDE-612.35', SOUTHSIDE-504.05, WESTSIDE-530.15

3. Year and Month(s) Liner Installed: JUNE, JULY, AUGUST 1981

4. Designer (Consultant): KOMEX CONSULTANTS LTD., DAVID J. FOOKES

5. Liner Type (i.e. Hypalon, HDPE, asphalt, etc.)
(if asphalt, indicate if sprayed or concrete)

PVC BOTTOM WITH REINFORCED HYPOLON ON SIDE WALLS.

6. Liner Supplier: SYNFLEX INDUSTRIES

7. Liner Manufacturer: DU PONT OF CANADA

8. Liner Installer: SYNFLEX INDUSTRIES

9. Liner Thickness: PVC-20 MIL BASIN REINFORCED HYPOLON-36 MIL SIDE-S

10. Liner Reinforcement/Scrim (if applicable) SIDEWALL'S HAD REINFORCED

HYPOLON, WITH SCRIM FOR REINFORCEMENT

11. Thickness and Type of Soil Cover over Liner: (if applicable)

12" SAND

12. Nature of Material/Waste Retained by Liner:

BRINE

Physical Properties: (grain size distribution, water content, etc.)

BRINE -SLIGHT HYDROCARBON CONTENT

Chemical Properties/Composition: BRINE

Dome Petroleum (cont'd)

13. Describe site preparation prior to liner placement:

- REGRADING OF POND
- STERILIZATRION OF SIDE WALLS
- DRAINAGE TRENCHES, PIPE AND SUMP
- PLACEMENT OF BEDDING SAND OR GEOTEXILE
- LAY LINER

14. Is liner installation considered successful? YES

Describe nature of liner defects (if any; if known):

NO SERIOUS PROBLEMS. LATE 1983 EXPERIENCED SMALL AREAS OF CONCENTRATED BLISTERS ON THE EXTERNAL LAYER OF THE SIDE WALLS (HYPOLON). THE SCRIM AND BOTTOM LAYER DID NOT SEEM TO BE AFFECTED AND NO LEAKAGE WAS EVIDENT. THESE "SPOTS" ARE TO BE PATCHED DURING 1984.

15. Describe any problems related to liner installation or operation of facility which might be liner related:

HAD A PROBLEM GETTING THE BASIN OF THIS POND DRY TO ENABLE US TO ACCOMPLISH DESIRED COMPACTION. USED A GEOTEXTILE TO COMPENSATE COMPACTION.

16. Was a monitoring system installed at the facility?

YES

If so, briefly describe results of monitoring (release rates/volumes etc.): (attach information if necessary)

AN ADJACENT POND IS UNLINED AND, AS SUCH, NO CONCLUSIVE RESULTS HAVE BEEN GATHERED TO DATE ON THE EFFECTIVENESS OF THE LINER.

APPENDIX F

TYPICAL WARRANTIES

-6

GUNDLE LINING SYSTEMS LTD.

WARRANTY

Warranty Number ____________________

Effective Date ____________________

GUNDLE LINING SYSTEMS LTD. warrants each ____________ Liner, which is manufactured and sold as first quality, and to be free from defects in materials, and to be able to withstand normal weathering from date of installation or sale for a period of ______ Years for _________ Mil ____________ under the normal uses and services for which it is designed and manufactured in any customary weather which may be encountered and which is not customarily considered to be in the nature of an Act of God; casualty or catastrophe such as (but not limited to): earthquake, flood, piercing hail, tornado, etc. Normal use and service excludes, among other things: the exposure of the liner to harmful chemicals; mechanical abuse by machinery, equipment or people; excessive pressure or stress from any source.

Should defects or premature loss of use within the scope of the above warranty occur, GUNDLE LINING SYSTEMS LTD. will at their option supply repair, or replacement material on a pro-rata basis at the then current price in such manner as to charge the Purchaser/User only for that portion of the warranted __________ Year life which has elapsed since he purchased the material. To enable GUNDLE LINING SYSTEMS LTD. technical staff to properly determine the cause of any alleged defect and to take appropriate steps to supply repair or replacement material for timely corrective measures, if such defect is within the warranty, any claim for alleged breach of warranty must be made in writing, by certified mail, to GUNDLE LINING SYSTEMS LTD. within thirty (30) days after the alleged defect was first noticed, or the defect and all warranties will be deemed to have been waived by the Purchaser/User. In the event repairs or replacements are to be effected, the lined area must be delivered to GUNDLE LINING SYSTEMS LTD. in a clean, dry unencumbered condition. This includes, but is not limited to: water, dirt, sludge, residuals or liquid of any kind.

GUNDLE LINING SYSTEMS LTD.'s liability under this warranty shall in no event exceed the amount of the sale price of the material sold to the Purchaser/User for the particular installation in which it failed, and under no circumstances shall GUNDLE LINING SYSTEMS LTD. have any liability for any special, direct, indirect, or consequential damages arising from loss of production or any other losses owing to failure of the material or installation, and no allowance will be made for repairs, replacement or alterations made by the Purchaser/User unless with GUNDLE LINING SYSTEMS LTD.'s consent in writing. GUNDLE LINING SYSTEMS LTD. neither assumes nor authorizes any person other than an officer of the Company to assume for it any other or additional liability in connection with the _____________ Liner. Any materials sold, other than as first quality, are sold as is and without warranty of any kind or nature. The warranties herein are given in lieu of all other possible warranties: express, implied, statutory or otherwise; and by accepting delivery of the materials, the Purchaser/User expressly waives all other such possible warranties except those specifically given herein; and Purchaser/User acknowledges thereby that the warranties given herein are accepted in preference to any all such other possible warranties.

SCHLEGEL LINING TECHNOLOGY, INC.

Schlegel®

WARRANTY AND LIABILITY LIMITATION

1. a. Seller warrants that SCHLEGEL® Sheet will, at the time of sale, conform to the specifications agreed by the parties and listed on Attachment A. If, within two (2) years of the date of completion of installation, Buyer demonstrates to Seller that all or part of the SCHLEGEL® Sheet supplied under the contract was not, at the time of sale, in conformance with the agreed specifications and that such non-conformance materially impairs the performance of the SCHLEGEL® Sheet under the uses and service conditions foreseen by both parties at the time of sale, Seller will either repair or replace, at its option, that portion of the SCHLEGEL® Sheet supplied under the contract which was not in conformance with the agreed specifications. Seller makes no warranty with respect to goods, materials or component parts which are not of its own manufacture.

   b. Seller further warrants that any SCHLEGEL® Sheet installation work it provides under the contract will be free from any significant defect in workmanship for a period of two (2) years from the date of completion of installation. If, within two (2) years of the date of completion of installation, Buyer notifies Seller of the discovery of any such defect, Seller will repair or replace that portion of the installation work shown by Buyer to be defective.

   c. Seller's obligations in 1.a. and 1.b. are conditioned on Buyer providing Seller with access to the area to be repaired or replaced, without charge, in such manner as to enable Seller to effect a proper repair or replacement.

   d. In the event Seller fails to supply repair or replacement materials within a reasonable time pursuant to its obligation in Section 1.a., or to effect a proper repair or replacement of installation work within a reasonable time pursuant to its obligation in 1.b., Seller shall instead refund that portion of the total contract price which relates to the nonconforming materials or defective installation work as the case may be.

2. If SCHLEGEL® Sheet is installed by other than Seller or a Seller-approved installation contractor in accordance with Seller's instructions (which will include the requirement that Seller's employees perform all joining and quality control functions), neither the Warranty in Section 1 nor any other warranty shall be in effect or enforceable against Seller.

3. **The obligations set forth in section 1 are exclusive and are in lieu of all other obligations, warranties and liabilities of Seller with respect to the condition or performance of SCHLEGEL® Sheet, including liability for negligence, strict liability in tort or otherwise, and all warranties of fitness for a particular purpose or merchantibility or otherwise, express or implied in fact or by law, which are hereby disclaimed.** Section 1 states Seller's entire and exclusive liability and Buyer's exclusive remedy for any claim of damage in connection with or resulting from the condition or performance of SCHLEGEL® Sheet delivered and installed pursuant to the contract. Statements in advertisements or catalogs are descriptive only and are not to be considered warranties.

4. Seller shall have no liability in any event for any special, indirect, incidental or consequential loss or damage.

5. The damages, penalties, indemnifications, liabilities, costs or expenses incurred by Seller as a result of any failure by Seller to meet its obligations under the contract or at law shall under no circumstances:

   a. Exceed in respect of any single type of liability such as delay, patent infringement, indemnification under hold harmless agreements, or any other type of liability, apart from the liability incurred pursuant to Section 1 above, five percent (5%) of the total contract price; or

   b. Exceed in aggregate, apart from liability incurred pursuant to Section 1 above, fifteen percent (15%) of the total contract price, or

   c. Exceed in the aggregate, including liability incurred pursuant to Section 1 above and all other liabilities under the contract or at law, the total contract price.

6. The provisions of this Enclosure shall supersede and govern all other provisions of the Agreement between Buyer and Seller regarding the purchase, sale and installation of SCHLEGEL® Sheet.

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Attachment "A"

SCHLEGEL LINING TECHNOLOGY, INC.

Schlegel®

WARRANTY AND LIABILITY LIMITATION

Warranty

Schlegel Lining Technology, Inc. ("Schlegel") warrants to Key Lake Mining Corporation (the "Customer") that the one hundred mil (100 mil) thick SCHLEGEL® sheet lining system and/or a combination of one hundred mil (100 mil) and eighty mil (80 mil) thick SCHLEGEL® sheet lining system sold and installed by Schlegel for the Key Lake Project, Contract C-169 (the "Project") will conform to the attached Minimum Specifications at the time of sale and will, as installed, be free from defects at the time of completion of installation and withstand the effect of normal weathering and usage for five (5) years thereafter.

Remedy if Schlegel Breaches The Warranty

If the Customer notifies Schlegel, in writing, during the Warranty period of a problem which it feels gives rise to a claim under this Warranty Schlegel will inspect the problem jointly with the Customer. If the Customer's claim is covered by this Warranty, Schlegel will repair or replace (at Schlegel's option, in the exercise of its best technical judgment) the defective material and/or installation work. If the problem is not covered by this Warranty, the Customer will be responsible for Schlegel's inspection expenses and the expenses of any repair or replacement which Schlegel and the Customer agree to carry out.

Conditions of this Warranty

This Warranty and Schlegel's obligations under it are subject to the following conditions:

- That the Customer notifies Schlegel promptly of the discovery of any problem which it feels gives rise to a claim under this Warranty;
- That the Customer provides Schlegel, without charge, with full and free access to the Warranty claim area (clean and dry and with fill and overburden removed if necessary) in order to enable Schlegel to inspect the same and, if appropriate, make a proper repair or replacement;
- That the lining system has been used at all times exclusively for the purpose for which it was originally intended and designed and in accordance with the normal uses and service conditions specified in the contract or the applicable Project specifications;

WARRANTY AND LIABILITY LIMITATION (cont'd)

- That no repair to the lining system (other than emergency repairs required to protect people or property) has been made or attempted by other than Schlegel's authorized personnel unless Schlegel has given its prior written consent;
- That the Customer has used reasonable care in the management, operation and safeguarding of the lining system; and
- That the Customer has paid Schlegel all amounts due under the contract.

Damages Excluded

This Warranty does not apply to materials or components not manufactured by Schlegel or to claims arising from: neglect, alterations by the Customer or others, subsurface conditions, faults, sinkholes, subsidence, abnormal design, structural defects of under-or-over-burden, abuse by equipment, machinery, people or animals, exposure of the sheet to harmful chemicals or alteration in the agreed or specified uses or service conditions, fire, flood, earthquake, hail, windstorm, explosion, tornado or other abnormal weather conditions, accident, vandalism or Acts of God.

Credit

In the event Schlegel fails to complete a proper repair or replacement within a reasonable time after good faith attempts pursuant to its obligations above, the Customer will be entitled to a refund of that portion of the total contract price which relates to the nonconforming or defective materials or installation work as the case may be.

Exclusion of Other Liabilities

This Warranty is exclusive. ALL OTHER WARRANTIES, INCLUDING WARRANTIES OF MERCHANTIBILITY, FITNESS FOR A PARTICULAR PURPOSE OR OTHERWISE, EXPRESS OR IMPLIED BY WORDS, AFFIRMATIONS OR OTHERWISE, ARE DISCLAIMED. (Samples, test results, statements in advertisements or catalogs, etc., are descriptive only and are not to be considered warranties.) Schlegel's obligations of repair, replacement or credit as set forth above are also exclusive and in lieu of all other obligations or liabilities (and constitute the Customer's exclusive remedy) with respect to the quality, condition or performance of SCHLEGEL® sheet.